SOUTHWEST FISHERIES CENTER ADMINISTRATIVE

REPORTS, 1976

SOUTHWEST FISHERIES CENTER ADMINISTRATIVE
REPORTS, 1976

CONTRIBUTION TO NMFS ANNUAL REPORT

Recent HL physiological studies using captive skipjack tuna show fish to be limited by water temperature and dissolved oxygen concentration. Skipjack tuna of all sizes appear to need water warmer than about 18°C with >3.5 ml/liter (5 ppm) dissolved oxygen; these two factors seem to define lower limit of normal habitat. Tunas are equipped with well-developed heat exchangers in blood circulatory systems that conserve body heat--freshly caught skipjack may have muscle temperatures 11°C above surrounding water. High internal temperature may limit ability to tolerate warm water--muscle protein may be damaged by internal temperatures above 35°C. Juvenile and adolescent skipjack can tolerate water 26°C or more and so can inhabit entire tropical Pacific, but adults may be limited. If they cannot find water cool enough and with enough oxygen in large areas of eastern Pacific, this would explain why only small skipjack are found there.

January 22, 1976

Southwest Fisheries Center Administrative Report No. 2H, 1976

ECONOMIC EVALUATION OF THE ROLL ON/ROLL OFF ANCHOVY TRANSPORT SYSTEM

Jerry A. Wetherall[1]

January 1976

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

INTRODUCTION

Growth of the skipjack tuna, Katsuwonus pelamis, industry in Hawaii is severely restricted by the availability of baitfish. Skipjack fishermen sacrifice from 35% to 40% of their potential fishing days competing for limited supplies of nehu, Stolephorus purpureus, the principal bait species now in use. Further, because nehu are extremely delicate no more than 75% of the nehu captured survive to be used as skipjack bait, and fishing trips of more than a day's length are not possible.

The scarcity and fragility of nehu not only limit the fishing time and range of the present fleet, but discourage investment in new vessels. Only one new vessel has joined the fleet in the past 20 years, while several boats have been retired.

Solution of the baitfish problem depends on success in two areas:

1. the technical development of alternative bait supplies at unit costs permitting substitution, and
2. the practical demonstration of the effectiveness of new baits and the building of confidence in their use among skipjack fishermen.

The second part of the solution requires that substitute baits be made available to skipjack fishermen in sufficient quantities to permit tests of key baitfish characteristics such as attractiveness to skipjack and survival in baitwells. The first part of the solution involves research in three areas:

1. appraisal of other local natural baitfish stocks (e.g., tilapia, Tilapia spp., and threadfin shad, Dorosoma petenense;
2. local artificial propagation of potentially suitable baitfishes (e.g., topminnows, Poecilia vittata);
3. development of long-range transport methods to make available to local fishermen baitfishes of proven quality which are abundant elsewhere (e.g., northern anchovy, Engraulis mordax, from California).

This report summarizes a preliminary economic assessment of a long-range transport system recently developed by the Honolulu Laboratory of NMFS's Southwest Fisheries Center to convey northern anchovy from California to Hawaii. The system involves shipping anchovy in a specially modified aircraft fuel tanker aboard Roll on/Roll off (hereafter referred to as RO/RO) freighters.

EVALUATION OF SUBSTITUTE BAITS

OPPORTUNITY COST OF NEHU

The evaluation of alternative bait supplies in economic terms requires the construction of a substitution curve, which indicates the unit costs of various substitute baits relative to nehu at different usage rates (Wetherall, MS[2]). However, because nehu are not purchased as are, say, fuel and fishing lines there is no market mechanism to measure the value of nehu to skipjack fishermen. Instead the worth of nehu must be appraised in terms of its

---

[2]Wetherall, J. A. Evaluation of bait substitution schemes in the Hawaiian fishery for skipjack tuna, Katsuwonus pelamis. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812. Manuscript in preparation.

opportunity cost. Wetherall (MS^2) has shown that the opportunity cost of nehu may be computed to a reasonable approximation as the product of three key factors:

1) the proportion of days spent baiting, 2) the ex-vessel price of skipjack, and 3) the amount of skipjack landed per unit of nehu used.

The feasibility of any alternative to nehu requires that the unit cost of that bait be no greater than the opportunity cost of nehu. Because the opportunity cost varies temporally a substitution scheme may not be feasible in all years or all seasons within a given year. Temporal variation in the opportunity cost of nehu is shown in Figures 1 and 2 and in Tables 1 and 2.

FEASIBILITY LINE

Two obvious conditions must be met to establish the feasibility of an alternative bait program during any time period: 1) as just discussed, the opportunity cost of nehu must not be less than the unit cost of the alternative bait, and 2) the quantity of bait produced by the scheme must not exceed the potential amount usable. Figure 3 shows how a particular hypothetical substitution scheme, producing bait at $4.50 per pound, generates a feasible period of about 7 months in an average year, 5 months in the spring and summer and 2 months at the end of the year. During this period, according to Table 2, about 190,000 pounds of bait could be used by the present skipjack fleet. For each point on the ordinate there is a different maximum usage rate. Together these form the feasibility line shown in Figure 4. Substitution schemes producing more bait

than can be used or producing bait at a unit cost exceeding the opportunity cost of nehu will fall in the infeasible region to the right of the feasibility line. The feasibility line may also be interpreted as the demand curve for bait in the skipjack fishery.

Evaluation of the RO/RO system in terms of its impact on the present skipjack fleet is now straightforward. First we compute the unit costs of delivering various quantities of anchovy during different seasons, and judge the feasibility of each system using the feasibility line. Then, for all feasible configurations we determine the reduction in time spent pursuing nehu, the corresponding increase in skipjack fishing time and the expected net economic gain to the skipjack fleet. The analytical methods for these steps are described by Wetherall (MS^2).

ANALYSIS OF UNIT DELIVERY COSTS IN THE RO/RO SYSTEM

THE RO/RO MODEL

Computing the unit costs of delivering anchovy via the RO/RO system requires the construction of a system model, which indicates the time sequencing of primary events of the RO/RO process and provides a framework for cost accounting. In the model used here the unit cost of delivering anchovy is a function of three factors: 1) the initial amount of bait purchased in California, 2) the overall bait survival rate, or the probability that any particular anchovy survives from purchase time until it can be used as live bait in Hawaii, and 3) the aggregate costs incurred in getting the

bait to Hawaii. The third factor is of course directly related to the first two, and the second may depend on the first also.

The main events or stages of the RO/RO process are ordered as

1. Bait acquisition and aging
2. Loading and shipment
3. Offloading and usage.

Mortality takes place during each stage and is particularly acute during the transitional periods when the anchovy are stressed from handling and crowding. The instantaneous mortality rate during each stage may depend on several factors including the extent and manner of handling, loading density, size of the fish, condition of gonads, water temperature, dissolved oxygen concentration, and so on. Neither the individual effects of the key survival parameters nor their interactions are well understood in the context of the RO/RO system. Further, variability in survival rates may be high even under the best possible handling practices and elaborate environmental controls.

COSTS

Associated with the sequence of major events in the RO/RO process is a sequence of annual operating costs, which may be classified as follows:

1. costs proportional to the amount of bait purchased;
2. costs proportional to the number of aging units;

3. costs proportional to the number of bait tankers;
4. costs proportional to the number of shipments;
5. costs proportional to the number of storage units;
6. costs proportional to the amounts of bait aged or stored; and
7. independent management and facilities costs.

In addition there are annual costs proportional to the total capital investment, such as depreciation, maintenance, insurance and debt service such as amortized capital expenses and interest. A detailed breakdown of estimated cost factors and the cost accounting for an example RO/RO system are presented in Table 3.

ASSUMPTIONS

In addition to the table of estimated cost factors, the analysis of the RO/RO system rested on a long list of assumptions, including

1. when aging is employed, anchovy are loaded into aging tanks at an assumed optimum density of 0.12 pounds per gallon (1,200 pounds per aging tank) and held for 20 days before shipment;
2. six aging tanks are required per tanker in the RO/RO system, when anchovy are aged;
3. only one RO/RO freighter is available, making one California-Hawaii round trip every 10 days;
4. up to four bait tankers may be transported on the RO/RO freighter during each crossing;
5. 1,700 pounds of anchovy are loaded into the tanker for each shipment (the assumed optimum load);

6. all anchovy delivered to Hawaii are used in skipjack fishing (i.e., no losses following delivery);
7. the difference in operating costs of skipjack vessel between a day spent fishing and a day spent baiting is $50;
8. the average amount of nehu in a bucket of bait, as reported by skipjack fishermen to the Hawaii Division of Fish and Game is 7 pounds;
9. pound for pound, anchovy are as effective as nehu in attracting skipjack;
10. the abundance of skipjack and the catch rate (pounds of skipjack caught per pound of nehu used) is equal to the 1968-73 average.

Some of these assumptions are relatively unimportant while others are critical to the final evaluations, as will soon be apparent.

ANALYTICAL PROCEDURE

The procedure adopted in the analysis of the RO/RO system was to

1. compute the expected amount of bait delivered and the cost per pound under many different configurations of the system (see below);
2. using the estimated feasibility line, determine the feasibility of each case;
3. for feasible systems, reallocate the potential fishing days and compute the net economic gain to the skipjack fleet; and
4. find the "best" feasible system in each class of systems, i.e., the one producing the greatest net economic gain to the skipjack fleet.

Under each system configuration the delivery scheme was simulated and costs were computed for increasingly longer "delivery seasons," beginning with a 1 month season coinciding with the period of highest opportunity cost and incrementing by periods of 1 month. Thus the performance of each configuration was examined under 3, 6, 9,..., 36 shipments. As expected, unit costs were inversely related to the scale of the system or number of shipments. Some system configurations were infeasible when run on a small scale, but feasible when more shipments were made. In some cases systems were judged to be feasible when of moderate scale, and then infeasible when enlarged because the bait delivered would exceed the estimated maximum amount usable by the present fleet. In all cases when simulated operations were expanded, the extension was into the month with the highest opportunity cost among the months still not included in the "delivery season."

SYSTEM CONFIGURATIONS

System configurations were created by varying certain model assumptions and conditions, as follows:

A. Survival Rates

1. Without aging

   a. Transport survival rate = 35%

   b. Transport survival rate = 50%

   c. Transport survival rate = 65%

2. With aging (aging survival rate = 45%)

a. Transport survival rate = 50%

b. Transport survival rate = 65%

c. Transport survival rate = 80%

B. Level of Capital Investment

1. 1-tanker system

2. 2-tanker system

3. 3-tanker system

4. 4-tanker system

C. Size of Bucket of Nehu

1. Standard - 7 pounds of nehu per bucket

2. 50% greater - 10.5 pounds of nehu per bucket

D. Relative Attractiveness

1. Standard - equal attractiveness

2. Pound for pound, anchovy only 67% as attractive as nehu

E. Skipjack Abundance

1. Standard - average abundance

2. Abundance 50% greater than average

3. Abundance 35% less than average

These alternative conditions combine in 288 ways. Each configuration was run under the 12 alternative "delivery seasons," so a total of 3,456 RO/RO systems were evaluated. The computations were done with the aid of a computer program.

RESULTS

BEST FEASIBLE SYSTEMS

The best feasible RO/RO systems among the cases examined are described in Table 4. The table gives estimates of the optimum number of shipments, the average unit delivery cost, the average net gain to the skipjack fleet and the average annual operating cost for each level of capital investment and each combination of assumptions on size of a nehu bucket, relative attractiveness, skipjack abundance and transport survival rate under the aging and no-aging options. Note that the actual capital investment is far greater for systems with aging than for those without.

The essential features of the table showing best feasible systems are summarized in Table 5. This gives the estimated net gain and unit production costs for 4-tanker systems under good, average and poor skipjack fishing years, under the most optimistic, most probable and most pessimistic conditions on bucket size and relative attractiveness (of those examined), and under the different aging and survival situations.

The analysis shows that during a year of average skipjack abundance a net gain to the fleet of about $385,000 could be achieved under the most optimistic set of conditions, and a gain as high as $810,000 might be obtained in a year of high skipjack abundance.

Under the most probable set of assumptions on bucket size and relative attractiveness (10.5-pound bucket; equal attractiveness), the expected gain is substantial under moderate transport survival

rates during a good year, but only marginal in a year of average catch rates.

Under the most pessimistic set of assumptions examined (10.5-pound bucket; anchovy only half as attractive as nehu) the only possibility of success would be with exceptionally high survival rates and then only during a year of high skipjack abundance.

There is a considerable difference in estimated costs and benefits between systems employing aging and those operating on a "load-and-go" basis. The aging method embodied in the RO/RO model utilized 10,000-gallon aging pools, six per tanker, and the anchovy were aged for 20 days prior to shipment. Because of the additional annual expenses for bait purchase, dock rental and electricity, labor and management, feed, and the greater capital investment the aging system studied here does not seem to provide any benefits over a no-aging operation, unless transport survival is increased at least 50% by the aging.

PRE-SEASON SHIPMENTS VERSUS SEASON SHIPMENTS ONLY

Because there is flexibility in the number of tankers which may be accommodated aboard a RO/RO freighter, there is an option to the strategy discussed above, in which shipments with up to four tankers were made only during the delivery season, when the anchovy could be profitably used by the skipjack fishermen. The alternative approach is to reduce the number of tankers per freighter crossing, but to begin shipments prior to the delivery season (when the unit cost would exceed the opportunity cost of nehu), storing the anchovy in

Hawaii and using them as rapidly as possible during the season. A choice between the two alternatives involves a trade off between investment in tankers and investment in storage facilities.

A study of the two approaches indicated that under the most optimistic conditions the pre-season shipment alternative was feasible, but that it was always inferior to the system employing season shipments only.

CONCLUSIONS

The analysis described here showed that under the most probable set of assumptions examined the RO/RO anchovy transport system could produce a significant increase in the skipjack fleet's profits provided

1. skipjack abundance was substantially greater than average, and
2. respectable survival rates could be achieved during transport (at least 50% when no aging is employed, at least 65% with aging).

Several weaknesses in the analysis may be noted:

1. The analysis examined only two assumptions concerning the size of a bucket of nehu--7 pounds per bucket, the figure used historically, and 10.5 pounds per bucket, a figure based on early results of sampling conducted under the direction of Thomas S. Hida (Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812) in 1974 and considered the most probable value. Since this analysis was done, Hida has augmented his information with new samples, and the data now

indicate that the average bucket contains 13.5 pounds of nehu. The effect of this greater value would be to increase estimates of the potential bait usage rates and to reduce estimates of the opportunity cost of nehu--and to diminish the feasibility of all RO/RO systems considered. The quantitative impacts have not been computed.

2. While the assumed survival rate during aging is firmly grounded in experience, the assumed survival rates during transport are based on expectation and on results of dockside shipment simulations. Observed survival rates during actual trial shipments have been lower than those examined here.

3. The analysis showed that the RO/RO system would be feasible only during years of high skipjack abundance, but did not consider the extra costs which would be incurred in operating the system on a periodic and irregular basis.

4. The analysis assumed that cost factors associated with the RO/RO system, skipjack fishing operations and nehu baiting, and the average ex-vessel price of skipjack will vary over time in a parallel fashion. Differential changes in these factors may alter the relative values of unit delivery costs and opportunity costs of nehu and change the feasibility picture for bait substitution schemes. For example, if automatic fishing poles become popular (they are now being used experimentally) the opportunity cost of nehu may increase significantly.

On balance, this study has shown that the RO/RO system would be feasible during good skipjack fishing years provided survival rates were increased so that at least 1,000 pounds of anchovy would be delivered in each tanker-load. The mortality problems may be solved through further research in system design and improved methods of bait selection and handling.

An important question not yet studied is the problem of forecasting the expected skipjack abundance and average catch rates during a season with enough lead time and precision to permit efficient and relatively risk-free use of the RO/RO system. (There is an obvious trade off here between precision of the forecast and potential economic benefits from substitution.) Of course, this problem is common to all substitution schemes which are feasible only intermittently, and this very likely means most schemes.

Two other problems of a general nature need attention. First, the attractiveness of northern anchovy, and other potential substitute baits, relative to nehu, needs to be established. If the larger anchovy are less effective than nehu, pound for pound, feasibility of the anchovy RO/RO system studied here will be diminished.

Second, the entire issue of acceptance of substitute baits by skipjack fishermen must be confronted. Several questions come to mind. For example, what is the maximum price the fishermen would be willing to pay for a pound of an alternative bait if it were demonstrably as effective as a pound of nehu? What relationship is expected between the price of various alternatives and percentage participation

of the fleet in a bait substitution scheme? For substitute baits which are shown to be feasible by the opportunity cost analysis, but which fishermen are not willing to buy at cost, what are the considerations underlying this barrier? What can be done to overcome them?

ACKNOWLEDGMENT

This work was completed under the supervision of Roger E. Green, leader, Baitfish Program (now at the Tiburon Laboratory, Southwest Fisheries Center) with the assistance of Marian Y. Y. Yong.

Table 1.--Variation in average opportunity cost of nehu (by month), proportion of days baited, aku caught per nehu used, ex-vessel aku price, aku caught per trip, and annual aku catch, for 1968-73.

	Year					
	1968	1969	1970	1971	1972	1973
Average opportunity cost ($/lb)						
January	2.25	4.39	1.60	3.27	4.46	3.43
February	2.22	3.48	4.63	2.58	4.83	7.05
March	2.80	3.30	2.22	4.50	7.43	6.18
April	2.83	3.58	2.49	4.59	8.60	7.78
May	2.84	2.84	2.85	6.17	7.85	7.58
June	3.01	3.50	2.74	7.40	6.87	7.93
July	2.66	3.05	4.24	6.08	7.23	8.34
August	3.32	2.50	3.43	4.67	7.85	6.86
September	2.85	2.61	4.80	4.51	4.97	3.35
October	3.34	2.56	4.01	5.02	4.37	4.96
November	3.16	2.58	4.79	7.00	5.41	6.60
December	5.10	2.89	3.78	6.72	7.31	7.37
Annual mean	2.98	3.05	3.61	5.38	6.51	6.80
Proportion of days baited	0.325	0.334	0.355	0.402	0.386	0.390
Aku caught per nehu used (lb/lb)	55.5	43.8	50.0	64.8	62.5	58.6
Ex-vessel aku price ($/lb)	0.165	0.209	0.203	0.207	0.270	0.297
Aku caught per trip (lb/trip)	4,163	3,327	3,836	6,475	5,763	5,588
Annual aku catch (metric tons)	4,218	2,692	3,332	6,004	4,948	4,859

Table 2.--Seasonal variation in proportion of days baited, aku caught per nehu used, average ex-vessel aku price, average opportunity cost of nehu, average aku catch, present bait usage rate and potential bait usage rate. Estimates are weighted means of bi-weekly statistics covering a 6-year period, 1968-73.

Month	Bi-weekly period	Proportion of days baited	Aku caught per nehu used (lb/lb)	Average ex-vessel price of aku ($/lb)	Average opportunity cost of nehu ($/lb)	Average aku catch (10^2 lb/2 weeks)	Present bait usage rate (lb/2 weeks)	Potential bait usage rate (lb/2 weeks)
January	1	0.340	31.6	0.325	3.49	1,126	3,562	5,397
	2	0.315	29.8	0.330	3.11	1,019	3,420	4,993
February	1	0.381	27.2	0.328	3.41	1,238	4,550	7,350
	2	0.351	30.8	0.397	4.30	756	2,455	3,782
March	1	0.361	24.3	0.432	3.78	642	2,640	4,132
	2	0.391	25.7	0.492	4.95	883	3,436	5,642
April	1	0.415	30.5	0.371	4.70	1,597	5,235	8,949
	2	0.378	44.2	0.284	4.74	2,651	5,997	9,642
May	1	0.380	51.9	0.238	4.69	4,520	8,709	14,046
	2	0.367	66.0	0.210	5.09	6,608	10,012	15,817
June	1	0.395	68.1	0.201	5.41	8,000	11,748	19,418
	2	0.378	76.4	0.184	5.32	9,995	13,083	21,033
July	1	0.375	78.5	0.195	5.74	9,931	12,651	20,241
	2	0.342	73.6	0.197	4.96	9,487	12,890	19,589
August	1	0.347	74.3	0.200	5.16	8,994	12,105	18,537
	2	0.367	57.5	0.207	4.36	6,090	10,592	16,733
September	1	0.367	52.9	0.208	4.04	4,177	7,895	12,472
	2	0.342	52.2	0.223	3.98	3,620	6,935	10,539
October	1	0.363	49.2	0.242	4.31	3,439	6,990	10,973
	2	0.352	47.4	0.245	4.09	3,435	7,247	11,183
November	1	0.369	49.6	0.255	4.66	2,767	5,579	8,842
	2	0.365	51.0	0.272	5.06	2,274	4,459	7,022
December	1	0.352	47.2	0.298	4.94	2,162	4,580	7,068
	2	0.377	37.3	0.430	6.04	1,268	3,399	5,455

Table 3.--Characteristics of two feasible RO/RO systems, one with aging and one without aging, in a year of high skipjack tuna abundance, and a breakdown of annual operating costs.

Characteristic	Without aging 50% transport survival	With aging 65% transport survival
1) Size of nehu bucket	10.5 lb	10.5 lb
2) Relative attractiveness	equal	equal
3) Skipjack abundance	50% above average	50% above average
4) Number of tankers	4	4
5) Number of aging tanks	0	24
6) Number of storage tanks	2	2
7) Number of shipments (crossings)	36	33
8) Bait delivered	122,400 lb	145,200 lb
9) Total capital investment	$57,900	$131,500
10) Annual operating costs:		
a. Bait purchase	$ 48,960	$ 99,280
b. Aging: dock rental	0	5,920
Aging: electricity	0	10,560
Aging: feed costs	0	68,380
Aging: total	0	84,860
c. Transport (freight, tractor rental, etc.)	231,800	212,500
d. Storage: dock rental	1,000	1,000
Storage: electricity	3,600	3,300
Storage: total	4,600	4,300
e. Labor: fixed	1,000	1,000
Labor: variable	24,000	36,670
Telephone, office management, etc.	3,000	4,500
Labor, management: total	28,000	42,170
f. Debt service, depreciation, maintenance, etc.	21,720	61,810
g. Total annual operating costs	335,080	504,920
11) Average unit delivery cost	$2.74/lb	$3.48/lb
12) Average net gain to fleet	$229,367	$176,679

Table 4.--Analysis of roll on/roll off anchovy transport systems. Multipliers indicate levels of key characteristics relative to standard conditions (System 1). Blanks indicate no feasible systems.

System number	Multipliers			Characteristics of best feasible systems															
				1 tanker CI = $22,800				2 tankers CI = $34,900				3 tankers CI = $46,400				4 tankers CI = $57,900			
	Size bucket	Relative attractiveness	Skipjack abundance	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$
Without aging; transport survival = 35%																			
1	1.0	1.0	1.0	--	--	--	--	21	4.63	8	117	24	4.20	28	182	30	3.95	53	284
2	1.5	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	1.0	1.0	1.5	30	5.33	32	96	36	4.32	112	187	36	4.03	187	261	36	3.88	262	335
5	1.0	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	--	--	--	--	21	4.63	10	117	24	4.20	31	182	30	3.95	58	284
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	1.0	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	1.5	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1.5	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Without aging; transport survival = 50%																			
1	1.0	1.0	1.0	30	3.76	23	96	36	3.05	91	186	36	2.84	156	261	36	2.74	221	335
2	1.5	1.0	1.0	--	--	--	--	--	--	--	--	21	3.02	15	162	24	2.85	31	232
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	1.0	1.0	1.5	36	3.67	99	112	36	3.05	237	186	36	2.84	374	261	36	2.74	512	335
5	1.0	1.0	0.65	--	--	--	--	--	--	--	--	21	3.02	7	162	21	2.89	18	207
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	30	3.76	25	96	36	3.05	96	186	36	2.84	163	261	36	2.74	230	335
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	--	--	--	--	30	5.82	33	148	30	5.38	66	206	33	5.12	108	287
10	1.0	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	1.5	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1.5	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Without aging; transport survival = 65%																			
1	1.0	1.0	1.0	36	2.83	68	112	36	2.35	173	186	36	2.19	279	261	36	2.11	384	335
2	1.5	1.0	1.0	21	3.09	5	71	30	2.40	47	158	33	2.21	95	241	33	2.13	138	309
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	24	4.26	23	169	27	4.03	44	239
4	1.0	1.0	1.5	36	2.83	162	112	36	2.35	361	186	36	2.19	561	261	36	2.11	761	335
5	1.0	1.0	0.65	--	--	--	--	30	2.40	37	158	33	2.21	78	241	33	2.13	116	309
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	36	2.83	70	112	36	2.35	179	186	36	2.19	287	261	36	2.11	396	335
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	30	5.50	27	91	36	4.40	100	174	36	4.08	168	242	36	3.92	237	310

Table 4.--Continued.

System number	Multipliers			Characteristics of best feasible systems															
				1 tanker CI = $41,800				2 tankers CI = $71,700				3 tankers CI = $101,600				4 tankers CI = $131,500			
	Size bucket	Relative attractiveness	Skipjack abundance	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$	Number of shipments	Unit cost $/lb	Gain K$	Operating cost K$
With aging; aging survival = 45%, transport survival = 50%																			
1	1.0	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	1.5	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	1.0	1.0	1.5	27	6.11	27	140	33	4.97	116	279	36	4.60	212	423	36	4.45	302	545
5	1.0	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	1.0	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	1.5	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1.5	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
With aging; aging survival = 45%, transport survival = 65%																			
1	1.0	1.0	1.0	--	--	--	--	30	3.89	52	257	30	3.65	102	361	33	3.48	167	505
2	1.5	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	1.0	1.0	1.5	36	4.49	96	178	36	3.79	248	300	36	3.55	400	422	36	3.43	552	544
5	1.0	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	--	--	--	--	30	3.89	56	257	30	3.65	109	361	33	3.48	177	505
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	--	--	--	--	--	--	--	--	24	6.44	37	255	30	5.90	80	390
10	1.0	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	1.5	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1.5	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
With aging; aging survival = 45%, transport survival = 80%																			
1	1.0	1.0	1.0	30	3.74	38	153	36	3.07	144	300	36	2.88	244	423	36	2.78	344	545
2	1.5	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	21	3.05	28	349
3	1.0	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	1.0	1.0	1.5	36	3.63	161	178	36	3.07	377	300	36	2.88	594	423	36	2.78	810	545
5	1.0	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	1.5	0.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	1.5	1.0	1.5	30	3.74	41	153	36	3.07	151	300	36	2.88	255	423	36	2.78	358	545
8	1.5	1.0	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	1.0	0.5	1.5	--	--	--	--	30	5.37	72	219	33	4.89	145	329	36	4.63	224	453
10	1.0	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	1.5	0.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1.5	0.5	0.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 5.--Summary of best feasible roll on/roll off systems under optimistic, most probable, and pessimistic sets of assumptions, during years of high, average and low skipjack abundance, and under different survival regimes. Upper figures are expected net gain to skipjack fleet (thousands of dollars) and lower figures, in parentheses, are expected unit delivery costs of transported anchovy (dollars per pound). Blanks indicate no feasible systems.

Skipjack abundance			High			Average			Low		
Assumptions on size of bucket and relative attractiveness			Optimistic	Most probable	Pessimistic	Optimistic	Most probable	Pessimistic	Optimistic	Most probable	Pessimistic
Survival rates during transport	Without aging	35%	262 (3.88)	58 (3.95)	-- --	53 (3.95)	-- --	-- --	-- --	-- --	-- --
		50%	512 (2.74)	230 (2.74)	-- --	221 (2.74)	31 (2.85	-- --	18 (2.89)	-- --	-- --
		65%	761 (2.11)	396 (2.11)	48 (4.03)	384 (2.11)	138 (2.13)	-- --	116 (2.13)	-- --	-- --
	With aging	50%	302 (4.45)	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --
		65%	552 (3.43)	177 (3.48)	-- --	167 (3.48)	-- --	-- --	-- --	-- --	-- --
		80%	810 (2.78)	358 (2.78	-- --	344 (2.78)	28 (3.05)	-- --	-- --	-- --	-- --

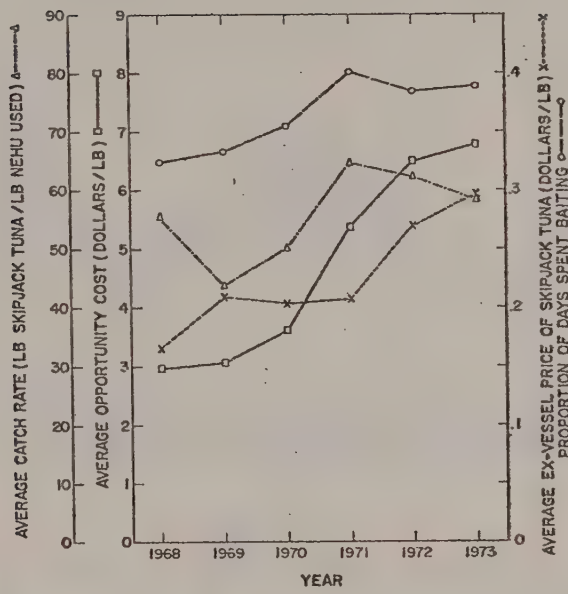


Figure 1.--Trends in the average annual opportunity cost of nehu and in its major components over 1968-73.

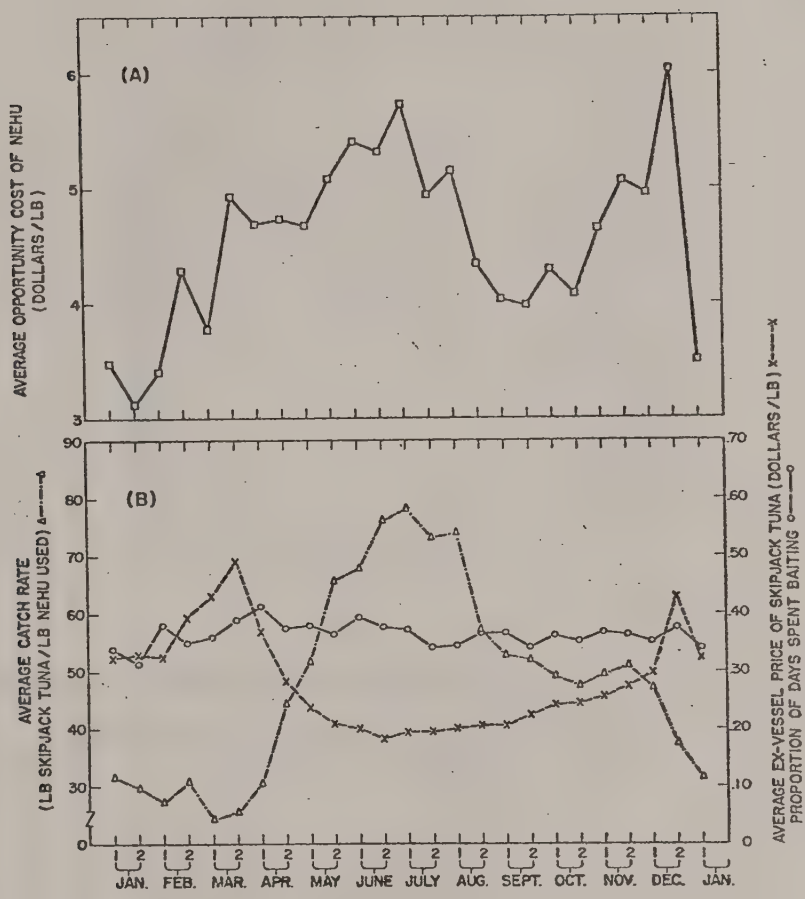


Figure 2.--The seasonal variation in A) opportunity cost of nehu, and B) its major components, based on biweekly statistics averaged over 1968-73.

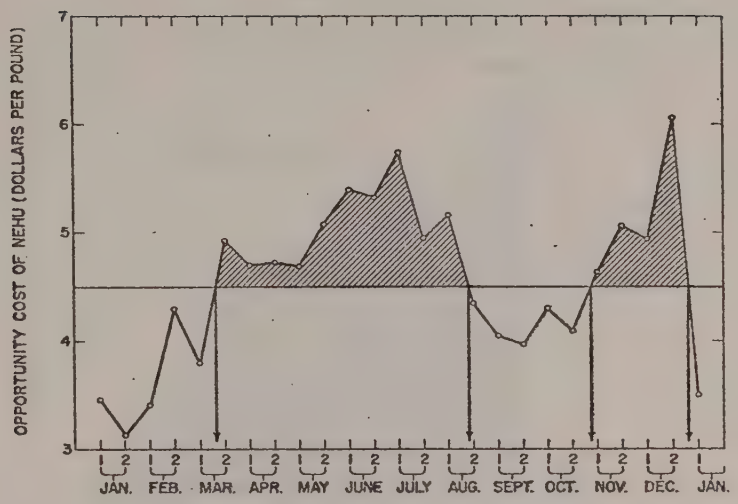


Figure 3.--The seasonal pattern in opportunity cost of nehu, averaged over 1968-73, showing the feasible period for bait substitution generated by a scheme producing bait at a cost of $4.50 per pound used.

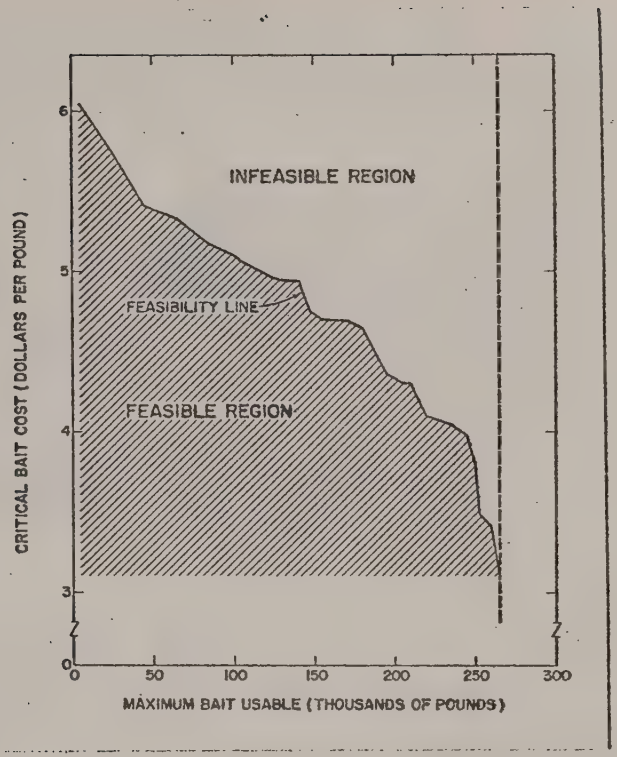


Figure 4.—The feasibility line for judging bait substitution schemes. Schemes falling in the infeasible region produce more bait than can be used in the feasible period generated. The feasibility curve is also the demand curve for bait in the Hawaiian aku fishery.

Southwest Fisheries Center Administrative Report No. 3H, Suppl. 1, 1976

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu and La Jolla Laboratories
P. O. Box 3830
Honolulu, Hawaii 96812

WORKSHOP ON THE POPULATION DYNAMICS OF NORTH PACIFIC ALBACORE

Honolulu, Hawaii, U.S.A.
10-12 December 1975

EXECUTIVE'S SUMMARY REPORT

May 1976

The status of the North Pacific albacore stock was assessed at a workshop held at the NMFS Honolulu Laboratory in December 1975. The workshop was part of an informal agreement between the Southwest Fisheries Center and the Far Seas Fisheries Research Laboratory, Shimizu, Japan, to promote and accelerate joint research on the North Pacific albacore stock. Participants included biologists from NMFS, FSFRL, California Department of Fish and Game, Oregon Department of Fish and Wildlife, Washington Department of Fisheries, and the Pacific Marine Fisheries Commission.

In recent years the total annual harvest of North Pacific albacore has risen to about 100,000 metric tons (MT), primarily due to expansion of the Japanese pole-and-line fishery, which took about 64% of the catch in 1974. The other major fisheries are the Japanese longline fishery (15%) and the United States troll and live-bait fisheries (21%).

The preliminary stock assessments discussed at the workshop were based on standard analyses of catch, effort, and size composition statistics.

The maximum sustainable annual yield for the North Pacific albacore stock was judged tentatively to be in the neighborhood of 115,000-125,000 MT. Thus the present annual catch is less than, but is approaching, the biological limits of the stock. The average yield per recruit could be increased if age at capture were increased, but this is infeasible under the present structure of the fisheries.

Recruitment to the North Pacific albacore stock shows a fourfold or fivefold annual variation. No relationship between recruitment and spawning stock can be demonstrated.

The joint investigations by the Honolulu Laboratory and the Far Seas Fisheries Research Laboratory will continue, focusing on critical research areas identified during the workshop. The fisheries will be monitored and stock assessments will be updated at regular intervals.

It was agreed that the continued cooperation among the fishery agencies of California, Oregon, and Washington in collecting and processing albacore fishery statistics is fundamental to the NMFS stock assessment capabilities and that every possible means (state and federal) should be taken to strengthen and support interstate and state-federal albacore programs.

The significant scientific contributions of the west coast albacore industry, through the American Fishermen's Research Foundation, were acknowledged and applauded at the workshop, and the need for continued government-industry cooperation was emphasized.

Southwest Fisheries Center Administrative Report No. 3H, 1976
(Revised)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu and La Jolla Laboratories
P. O. Box 3830
Honolulu, Hawaii 96812

REPORT

of the

WORKSHOP ON THE POPULATION DYNAMICS OF NORTH PACIFIC ALBACORE

Honolulu, Hawaii, U.S.A.

10-12 December 1975

May 1976

CONTENTS

1. Opening of the workshop 1

2. Adoption of agenda and distribution of working documents 1

3. Review of basic statistical information 2

4. Recent trends in the fisheries 5

5. Status of the stocks 7

5.1 Production model analysis 7

5.2 Yield per recruit assessment 9

5.3 Stock and recruitment 11

5.3.1 Spawning biomass 11

5.3.2 Recruitment 11

5.3.3 Stock-recruit relations 11

5.4 Sustainable yields 11

5.5 Summary of yield per recruit and stock-recruitment assessments 12

6. Summary and recommendations for future work 13

6.1 Data from the U.S. fishery 13

6.2 Data from the Japanese fisheries 14

6.3 Data from other fisheries 14

6.4 Further production model analysis 14

6.5 Further cohort analysis 14

6.6 Indexing recruitment and stock fecundity 15

6.7 Impact of environmental factors 15

6.8 Socio-economic considerations in interpretation of data 15

6.9 Problems in measuring effective fishing effort 15

7. Future activities

Appendix A. List of participants 16

Appendix B. Agenda 17

Appendix C. List of background documents 18

1. Opening of the Workshop

1.1 The workshop was conducted at the National Marine Fisheries Service (NMFS) laboratory in Honolulu, Hawaii, on 10-12 December 1975, as part of an informal agreement established in 1974 between the Southwest Fisheries Center, NMFS and the Far Seas Fisheries Research Laboratory of the Japan Fisheries Agency to promote and accelerate joint investigations into the population dynamics of North Pacific albacore. Participants at the workshop included representatives of the Southwest Fisheries Center, the Far Seas Fisheries Research Laboratory, the California Department of Fish and Game, the Oregon Department of Fish and Wildlife, the Washington Department of Fisheries, and the Pacific Marine Fisheries Commission. A complete list of participants is given as Appendix A to this report.

1.2 Richard S. Shomura, Director of the Honolulu Laboratory, welcomed the participants, reviewed the terms of reference for the workshop, and set out the objectives, which were

a. To produce a rapid, preliminary assessment of the status of the North Pacific albacore stock in terms of standard equilibrium yield and yield per recruit criteria,

b. To identify weaknesses in the preliminary assessments, and,

c. To recommend a set of goals for the next phase of the cooperative research program.

1.3 Jerry A. Wetherall, head of the North Pacific albacore population dynamics task at the Honolulu Laboratory, acted as chairman of the workshop. He appointed Gary T. Sakagawa of the Southwest Fisheries Center, La Jolla and Robert A. Skillman of the Honolulu Laboratory as rapporteurs.

1.4 The workshop participants agreed that the tentative nature of the preliminary assessments should be explicitly emphasized, and that the results reported here should be treated circumspectly.

2. Adoption of Agenda and Distribution of Working Documents

2.1 The workshop agenda, as adopted by the participants, is given as Appendix B. A list of the working papers distributed to participants and reviewed during the workshop is presented in Appendix C.

3. Review of Basic Statistical Information

3.1 Statistics from the Japanese pole-and-line and longline fisheries and the United States bait and troll fisheries for North Pacific albacore were presented. Rather complete and comparable statistics on the magnitude and size composition of catches from the United States and Japanese fisheries are available at least since the late 1940's. Nominal effort statistics by month and 5° square of longitude and latitude are available in the longline fishery beginning with 1952, and nominal effort measures are also available for the United States and Japanese surface fisheries.

3.2 Table 1 summarizes catch statistics since 1961 and Table 2 presents standardized catch-per-unit-effort (CPUE) and effort as given by Shiohama and Morita (background document NPALB/75/2). Some length-frequency distributions for the Japanese pole-and-line fishery are shown in Figure 1, and Table 3 shows annual statistics on mean length for fish taken in the major Japanese and United States fisheries.

3.3 In addition to the substantial landings by the Japanese pole-and-line and longline fleets and the United States troll and bait vessels, minor quantities of North Pacific albacore are taken by other Japanese fisheries, by United States sport fishing boats and by vessels from Canada, South Korea, and Taiwan. These catches are judged to comprise less than 5% of the total landings, and were not included in analyses. However, Canadian landing statistics are presented in Table 1.

Table 1.--Catch statistics in metric tons for North Pacific albacore fisheries, 1961-75.

Year	Japan			United States	Canada[1]	Total
	Pole and line	Longline	Other gears[1]			
1961	18,636	15,999	--	14,891	4	49,530
1962	8,729	12,617	--	20,838	1	42,185
1963	26,420	11,445	--	27,574	5	65,444
1964	23,858	11,558	--	21,800	3	57,219
1965	41,491	11,214	121	16,878	15	69,719
1966	22,830	20,874	585	16,769	44	61,102
1967	30,481	24,374	520	21,927	161	77,463
1968	16,597	19,040	1,109	25,347	1,028	63,121
1969	31,912	15,169	1,480	21,822	1,365	71,748
1970	24,263	12,695	956	25,455	354	63,723
1971	52,957	9,083	1,262	24,267	1,587	89,156
1972	60,591	10,594	922	31,026	3,547	106,680
1973	69,640	13,855	1,922	18,506	--	103,923
1974	73,576	[2]17,000	--	24,494	--	[2]115,070
1975	[2]45,000	[2]17,000	--	[2]25,000	--	[2]87,000

[1]Dashes indicate no estimates available.

[2]Preliminary estimates.

Table 2.--Standardized catch-per-unit-effort (CPUE) and effort statistics for North Pacific albacore fisheries, 1961-72.

Year	Standardized CPUE[1]			Standardized effort[2]			
	Japan		United States	Japan		United States	Total
	Pole and line	Longline		Pole and line	Longline		
1961	0.6832	1.6875	0.6105	27,278	9,303	24,391	60,972
1962	1.1211	1.0938	0.7368	7,786	11,532	28,282	47,600
1963	0.9767	1.0938	0.8947	27,050	10,464	30,819	68,333
1964	1.0652	1.5313	0.7368	22,398	7,548	29,587	59,533
1965	0.9720	1.2500	0.6947	42,686	8,971	24,295	75,952
1966	0.9224	2.3750	0.6421	24,751	8,789	26,116	59,656
1967	0.9457	2.9063	0.8526	32,231	8,387	25,718	66,336
1968	0.8292	1.9063	0.9684	20,016	9,988	26,174	56,178
1969	0.7686	1.7813	0.8632	41,520	8,516	25,280	75,316
1970	0.9519	1.1563	0.9579	25,489	10,979	26.574	63,042
1971	1.0776	0.8125	0.8737	49,143	11,179	27,775	88,097
1972	0.9705	1.0313	1.1789	62,433	10,272	26,318	99,023

[1]Nominal CPUE for each year divided by average CPUE over 1970-72.

[2]Catch (Table 1) divided by standardized CPUE.

Table 3.--Estimates of mean fork length (cm) of North Pacific albacore taken in United States and Japanese fisheries, 1952-73.

Year	Japanese pole-and-line	Japanese longline	United States
1952	74.7	81.6	68.5
1953	79.6	87.5	66.7
1954	82.5	84.5	65.6
1955	79.4	87.9	63.5
1956	74.4	85.4	68.0
1957	78.0	84.7	71.9
1958	79.0	87.0	70.0
1959	83.7	91.2	66.3
1960	79.0	89.5	70.2
1961	82.6	90.1	73.7
1962	89.3	88.0	65.2
1963	78.6	87.4	67.5
1964	76.2	86.8	70.2
1965	83.5	84.9	71.1
1966	82.6	86.1	69.9
1967	84.2	89.0	68.0
1968	82.6	87.0	68.0
1969	81.7	92.0	69.3
1970	74.4	87.9	69.0
1971	76.7	96.3	65.9
1972	83.2	92.7	71.5
1973	77.8	--	--

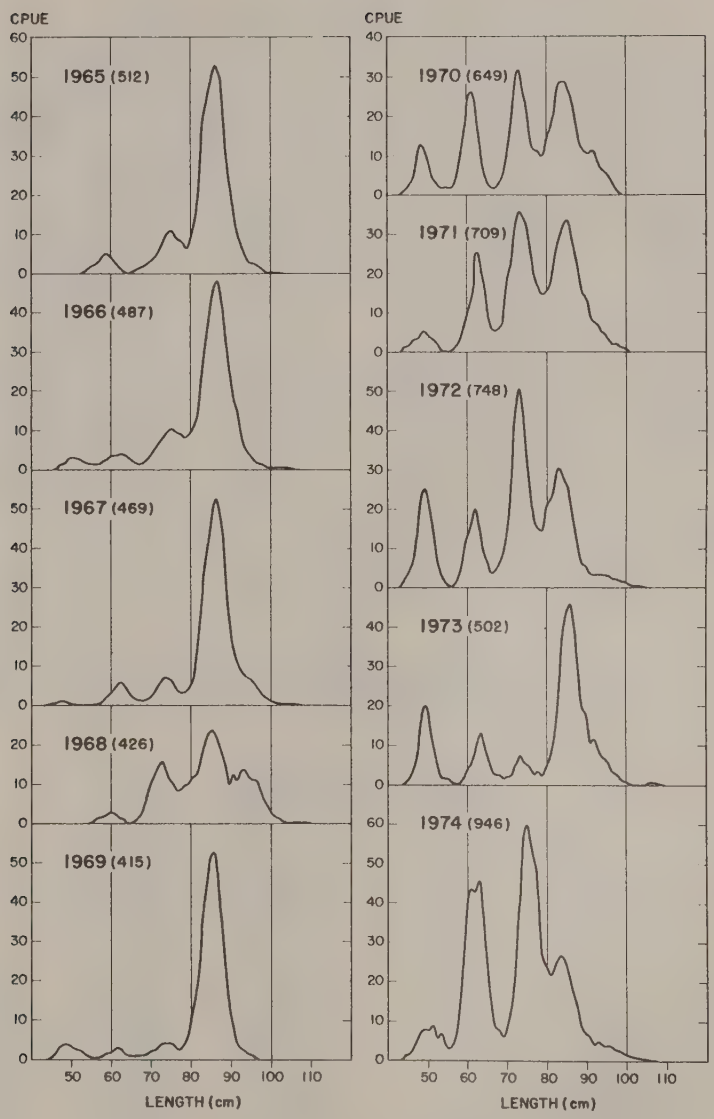


Figure 1.--Length-frequency distributions for North Pacific albacore taken in the Japanese pole-and-line fishery, 1965-74, in catch per fished day (CPUE). Annual mean CPUE also given.

4. Recent Trends in the Fisheries

4.1 Japan and the United States are the principal nations fishing for albacore in the North Pacific. In recent years about 100,000 metric tons (MT) have been landed annually. The Japanese pole-and-line fishery took about 64%, the Japanese longline fishery 15% and the American troll and bait fishery about 21% of the total catch landed in 1974.

4.2 The number of boats in the Japanese pole-and-line fleet fluctuated between 510 and 582 during 1965-73 (Table 4). Since 1971, there has been a marked decrease in the number of boats in the 20-50 and 100-200 gross tons (GT) classes and a marked increase in the number of boats in the 50-100 GT class and especially in vessels greater than 200 GT. Vessels greater than 200 GT have a greater operating range and better refrigeration and bait-holding capabilities than smaller vessels. The impetus for this increase in large boats has been the expansion of the southern water skipjack tuna fishery to meet the foreign and Japanese domestic demand for skipjack tuna.

Table 4.--Number of Japanese albacore pole-and-line vessels by size class.

Year	Total	Size of vessel (gross tons)			
		20-50	50-100	100-200	>200
1965	572	298	91	148	35
1966	571	299	71	167	34
1967	564	296	54	173	41
1968	561	276	60	170	55
1969	528	248	71	156	53
1970	512	220	91	140	61
1971	510	165	133	129	83
1972	554	131	162	116	145
1973	582	93	210	80	199

4.3 Effective fishing effort on North Pacific albacore by the Japanese longline fishery shows a downward trend during 1967-72 (Figure 2). This is primarily due to a shift of fishing effort onto North Pacific bigeye tuna in response to increased prices for this species which is sold for "sashimi" in the Japanese domestic market (NPALB/75/1). In coming years, however, it is likely the Japanese longline effort on albacore will level off or even increase. Albacore is gaining in popularity with the Japanese consumer primarily

when canned in oil, but also partially dried, and as sashimi. If this continues, the fleet will probably refocus fishing effort onto albacore to meet the domestic demand.

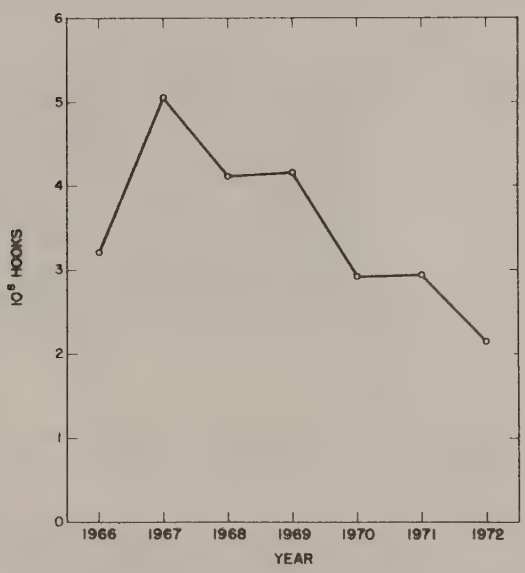


Figure 2.--Effective fishing effort in the Japanese longline fishery for North Pacific albacore, 1965-72.

4.4 Catch by the U.S. fishery has fluctuated over the years but within a relatively narrow range (Table 1). The fleet consists of approximately 2,000 vessels that fish for albacore. Most of these boats fish for salmon, crab, and other fish species as well. Trollers make up about 95% of the U.S. albacore fleet, and land about 75% of the catch.

4.5 Recent exploratory fishing surveys have shown that the catch can be increased by starting the U.S. troll fishery early in offshore fishing areas. In fact exploratory fishing has been carried out as far west as the Kuroshio front area (north of lat. 30°N, long. 140°E-180°). If this practice is widely adopted by the fleet, then we can expect fishing pressure to increase in the near future.

4.6 U.S. albacore fishermen actively support and finance government-industry research programs with the objectives of increasing the efficiency of albacore fishing and developing scientific information for albacore conservation. Greater efficiency in searching out and following concentrations of albacore is assisted by preseason forecasts, intraseason monitoring of the fishery and the fishing environment, and the widespread use of modern shipboard communications equipment. In addition, some fishermen are adopting new labor-saving gear, such as automatic fishing poles. With these developments it is likely that the effectiveness of a day's fishing in the U.S. albacore fishery is increasing, and an overall increase in the effective fishing effort of U.S. vessels may be expected.

4.7 Besides these developments, there are other considerations that should be mentioned here because they have a bearing on the future of the North Pacific albacore fisheries. Paramount is the fact that many nations besides Japan and the United States have tuna fleets that are large, highly mobile, and capable of exerting considerable fishing pressure on a stock. Currently these other fleets, e.g., the longline and pole-and-line fleets of Taiwan and South Korea, are not participating in the North Pacific albacore fisheries to any significant degree. However, as the available world supply of tunas begins to level off, and fishing regimes under extended fishery jurisdiction become clearer, it is likely that greater participation by those fleets will occur, accompanied by a considerable increase in fishing pressure upon the stock.

5. Status of the Stocks

5.1 Production model analysis

5.1.1 The analysis discussed in this section is based on NPALB/75/2 and on computations made during the workshop. While analyses for the Japanese pole-and-line fishery, the Japanese longline fishery, and combined North Pacific albacore fisheries were presented, most discussion related to the latter case.

5.1.2 The generalized production model of Pella and Tomlinson was fitted to the catch data and fishing effort statistics derived from the CPUE statistics in Table 2. A computer program, PRODFIT, by W. W. Fox, Jr., Southwest Fisheries Center, La Jolla, was used.

5.1.3 Two procedures were followed in estimating fishing effort. First normalized annual CPUE statistics for each fishery were derived by computing an average CPUE over the period 1970-72 and dividing this into the nominal annual CPUE statistics. It was suggested that 1970-72 were not typical years in the fishery and that the use of an average CPUE over all the years would be preferable.

In addition, since the CPUE time series differed markedly among the three principal fishing areas of the Japanese pole-and-line fishery, it was felt that a better procedure would be to normalize the CPUE statistics for each area separately (Figure 3). Relative standardized fishing effort was estimated by dividing the annual catch for each fishery by the corresponding normalized CPUE (Table 1) and summing over fisheries.

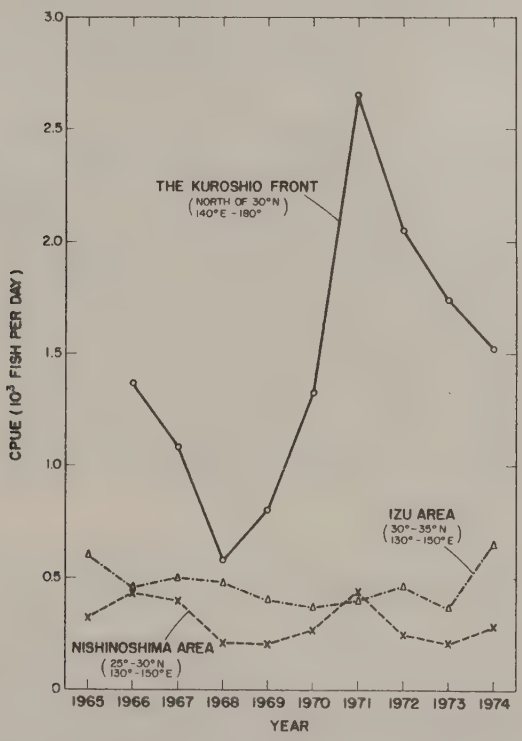


Figure 3.--Annual average catch rates (number of fish per fishing day) in the Japanese pole-and-line fishery for North Pacific albacore, 1965-74, by major fishing grounds.

5.1.4 This procedure resulted in a CPUE/effort relationship showing no decline in apparent stock density with increased fishing effort, so no production model was fitted to the data. Another standardization procedure and a division of the Japanese pole-and-line fishery into its three components might give different results.

5.1.5 Second, overall fishing effort was standardized to units of effort in the Japanese pole-and-line fishery, since this fishery accounts for a majority of the harvest and operates on fish as young as those taken in the United States fishery and as old as those comprising the bulk of the longline catch. Overall fishing effort was obtained by dividing aggregate catch (Table 1) by the observed CPUE of the pole-and-line fishery (Table 2). CPUE seems inversely related to effort. The size composition of the Japanese pole-and-line catch changed markedly following the expansion of the fishery into the Kuroshio front area, where smaller fish predominate. The effect of such changes on assessments using the production model has not been determined.

5.1.6 The generalized production model was fitted to the data with the parameter "m" fixed at 0.0 (asymptotic curve), 1.001 (Gompertz curve), 2.0 (logistic curve), and also with "m" variable. The equilibrium approximation method was used, with the albacore assumed to contribute significantly to the catch for 3 or 4 years. This preliminary analysis provided no guidance on choosing among the different shapes of the production curve, since residual mean squares were the same. All solutions indicated a maximum sustainable average yield (MSAY) of 100,000-115,000 MT. These are regarded as rough, preliminary estimates. Further detailed study including evaluation of alternative standardization procedures and assumptions, as indicated above, is required.

5.2 Yield per recruit assessment

5.2.1 A cohort analysis of year-class catch histories was conducted to estimate age-specific fishing mortality rates (NPALB/75/3). Estimates of F were obtained on a quarterly basis over an 8-year period of exploitable life (age 2.5 years through age 10.5 years), and under different assumptions on natural mortality rate (M, both constant and age-specific) and fishing mortality rate during the last age interval (F_o from age 10.25 to 10.50 years). The catch histories were constructed from pooled catch and size composition statistics from the United States fishery and the Japanese pole-and-line and longline fisheries. Statistics for the years 1952-72 were used, so complete 32-quarter catch histories were produced for the 1949-62 year classes. The same sets of assumptions on M and F_o were applied to each catch sequence.

5.2.2 Age-specific F vectors for fishing years 1959-65 were averaged to establish base conditions for a yield per recruit assessment; estimates of F for more recent years were derived from shorter catch sequences and were considered less reliable.

5.2.3 A choice of the most reasonable assumptions on F_0 was made by comparing estimates of F generated under each alternative set of assumptions with independent estimates of F obtained through an analysis of age-specific catch rates in the longline fishery, and by a consideration of tag recovery rates in recent experiments by NMFS and the American Fishermen's Research Foundation. Of the sets of assumptions examined, the most reasonable were considered to be $F_0 = 0.01$ with $M = 0.2$ at all ages, and $F_0 = 0.10$ with $M = 0.2$ from ages 2.5 years through 5.5 years, and then increasing progressively for older albacore.

5.2.4 An assessment of yield per recruit was made using the two chosen F vectors. The two vectors gave almost identical results. They produced an estimated base period (1959-65) yield per recruit of 4.4 kg and indicated that the stock was underfished, in a yield per recruit sense, in the mid-1960's. Table 5 shows the estimated responses of the yield per recruit to various fishery-specific increases in fishing mortality and changes in assumed length at first capture. A doubling of fishing mortality rates in all fisheries over the base period levels would have been expected to produce a 35% increase in yield per recruit over base conditions, and a slightly greater average yield per recruit if minimum size were also increased. Similar results would be obtained with a threefold increase in fishing mortality rates in the United States fishery and the Japanese pole-and-line fishery and no change in the longline mortality rates. The analysis indicated that further increases in average fishing mortality would produce only slightly greater yield per recruit, unless average size at capture was increased.

Table 5.--Percentage changes in average yield per recruit expected under various alterations in fishery-specific fishing mortality rates and assumed minimum size at capture, relative to conditions in mid-1960's base period.

Minimum length at capture (cm)	Fishery-specific F-multipliers (U.S., pole and line, longline)			
	(1.0, 1.0, 1.0)	(1.5, 1.5, 1.5)	(2.0, 2.0, 2.0)	(3.0, 3.0, 1.0)
59	Base yield per recruit, 4.4 kg	+22%	+35%	+36%
71	-4%	+21%	+38%	+40%

5.3 Stock and recruitment

5.3.1 Spawning biomass.--Estimates of spawning biomass from the cohort analysis, assuming F_0 constant over years, suggested that the biomass of albacore older than 6 years decreased in the early 1950's, was relatively constant from the mid-1950's until 1966 and then increased markedly, at least through 1968 (more recent estimates were less reliable). This pattern in estimates of spawning biomass is remarkably consistent with trends in average catch rates of mature albacore in the Hawaiian longline fishery and with the annual pattern of catch rates by Japanese longliners in the subequatorial spawning area.

5.3.2 Recruitment.--Estimates of recruitment from the cohort analysis of 2.5-year-old albacore suggest a fivefold variation in strength of year classes, with peak recruitments every 4 or 5 years.

5.3.3 Stock-recruit relations.--Plots of estimated recruitment against spawning biomass show a wide scatter. Ricker stock-recruit models fit better to data points generated under assumptions of age-specific natural mortality than under constant M.

5.4 Sustainable yields

5.4.1 Surfaces of sustainable average yield were estimated (NPALB/75/4) by coupling the yield per recruit model with two alternative stock-recruit relations: (1) The Ricker model associated with the chosen conditions on M and F_0, and (2) a linear-segmental model giving constant recruitment at all but very low levels of spawning biomass, and at these low levels a sharply reduced recruitment.

5.4.2 The maximum sustainable average yield was estimated to be about 100,000 MT under the Ricker model and approximately 115,000 MT under the linear-segmental stock-recruitment relation. Under the latter model, the maximum yield is achieved at a greater average fishing mortality rate and a lower average age at capture than under the Ricker option.

5.4.3. Estimated sustainable average yields under different fishery-specific fishing mortality multipliers are given in Table 6. Under the assumed base period conditions (1959-65) the average yield was about 70,000 MT. With a threefold increase in fishing mortality in the United States and pole-and-line fisheries, and a 50% reduction in the longline fishing mortality rate, an average yield of about 90,000 MT could be sustained as long as recruitment was not reduced. With reduced recruitment, under the Ricker model, yields would not be sustainable. The analysis indicated clearly that a maximum yield policy, unconstrained by economic and political considerations, would involve a concentration of effort on older age groups.

Table 6.--Estimated sustainable yields expected under two alternative stock-recruit models (Ricker and linear-segmental) and various assumed changes in fishery-specific fishing mortality rates.

Spawner-recruit model	Fishery-specific F-multipliers			Average age at capture (yr)	Average fishing mortality rate	Sustainable average yield 10^3 MT per year
	U.S.	Pole and line	Longline			
Ricker	1	1	1	4.8	0.20	70
Lin-seg	1	1	1	4.8	0.20	71
Ricker	2	2	0.5	4.3	0.32	77
Lin-seg	2	2	0.5	4.3	0.32	82
Ricker	3	3	0.5	Yields not sustainable		
Lin-seg	3	3	0.5	4.0	0.49	90
Ricker	0	0	6	5.4	0.30	96
Lin-seg	0	0	10	4.9	0.45	109

5.4.4 In recent years the North Pacific albacore harvest has increased from the 70,000 MT level to approximately 100,000 or 110,000 MT. Because of lags in the response of the stock to changes in mortality rates, such transitional yields are perhaps greater than the sustainable average yields to be expected under assumed increased levels of fishing mortality. Simulation studies showed that a 50% increase in fishing mortality rates (in all fisheries) over base period conditions would have produced an increase in yield from the 70,000 MT level to 100,000 MT in the first year. However, under both stock-recruit options simulated annual yields then declined to an equilibrium level of 85,000 MT. When fishing mortality rates were increased further to a level twice as great as during the base period, the simulated yield increased in the first year to about 110,000 MT and then settled gradually to a steady level of 92,000 MT under constant recruitment. Under the Ricker stock-recruitment relation, the simulated yield was increased in the first year to a similar high level but then underwent a steady reduction with no equilibrium achieved.

5.5 Summary of yield per recruit and stock-recruitment assessments

5.5.1 The analyses indicated that during the mid-1960's the North Pacific albacore stock was underfished in a yield per recruit sense and in terms of total equilibrium yield. Maximum sustainable average yields are judged roughly to be between 100,000 and

125,000 MT. These would be achieved with an average age at capture between 5.5 years and 6.0 years, and an average fishing mortality rate between 0.25 and 0.40, depending on the assumed stock-recruitment relationship. During the mid-1960's base period, the average age at capture was about 4.8 years and the average fishing mortality rate about 0.2. Achievement of the maximum sustainable yield would require a concentration of fishing mortality on older age groups, a situation presently infeasible.

5.5.2 The equilibrium yield levels associated with recent increases in fishing effort in the surface fisheries are not yet known. Whether recent levels of harvest can be sustained under the prevailing average age at capture and the present effort depends critically on the relationship between stock and recruitment.

5.5.3 The assessments stemming from the cohort analysis and yield per recruit investigation are based on several assumptions needing close scrutiny. In particular, it is recommended that the cohort analysis be repeated using alternative procedures for constructing catch histories, including examination of different growth models. It is suggested further that a detailed evaluation of recent tagging results be undertaken to strengthen understanding of age-specific fishing mortality rates. In addition the assumption of constancy in the fishing mortality rate on 10-year olds during the fourth quarter of each year should be critically evaluated.

5.5.4 More definitive assessment of North Pacific albacore will require a better understanding of fluctuations in recruitment and changes in the reproductive capacity of the stock. It is recommended that indices of recruitment be developed and that such indices be checked for consistency by comparison with subsequent catch rates in the longline fishery. It is further recommended that stock-fecundity indices be developed, taking into account possible age-specific differences in relative fecundity and in sex ratio.

6. Summary of Recommendations for Future Work

Several recommendations were discussed by the participants and are summarized here for easy reference.

6.1 Data from the U.S. fishery.--Improved procedures are currently being used by California, Oregon, and Washington in collecting and compiling catch, catch and effort, and length-frequency statistics from the U.S. fishery. These data are vital for determining the status of the North Pacific albacore stock and for formulating timely management advice. This will be especially critical in the coming years when fishing effort may increase at an accelerated rate and the stock may become more heavily exploited. It is essential, therefore, that collection, compilation, and dissemination of the U.S. fishery

data on a timely basis be continued. The participants recommended that catch, catch per unit effort, and length-frequency data continue to be collected and compiled by the States and the data be made available to concerned scientists on a timely basis. The participants also recommended that the detailed procedures for collection, compilation, and dissemination of the data be discussed among the parties concerned with Dr. R. M. Laurs acting as coordinator.

6.2 Data from the Japanese fisheries.--Complete data on catch and nominal effort from the longline and pole-and-line fisheries are published annually by the Japanese. The length-frequency statistics for both fisheries are published at regular intervals. However, neither the longline data nor the pole-and-line data are yet available on a timely basis (at least 2 years old when published). The participants recommended that emphasis be placed on obtaining at least catch data from the Japanese fisheries on a more timely basis.

6.3 Data from other fisheries.--Complete statistics, especially on the catch, from all fisheries that exploit the North Pacific albacore stock are important in analyses of the status of the stocks. Currently, only a few thousand tons of North Pacific albacore are caught by nations other than Japan and the United States. The exclusion of this catch from current analyses does not significantly affect the results. But this will not be the case if this catch increases in the future, and this can be determined only if the catch is monitored. The participants, therefore, recommended that data on the catch from other nations, i.e., Canada, Taiwan, and Korea, that fish for albacore in the North Pacific Ocean be obtained.

6.4 Further production model analysis.--The production model analysis is a widely used technique in tuna stock assessment. It has the virtue of requiring relatively little data while yielding a general understanding of the status of the fishery. The participants recommended that further work be done on the application of the production model to the North Pacific albacore fishery. Refinements such as the treatment of CPUE of the three Japanese pole-and-line fishery areas separately in the effort normalization procedure and the use of total catch from all fisheries should be introduced. For the long term, however, detailed analyses of CPUE from the different fisheries as measures of relative abundance are required, and the participants recommended that such analyses be initiated.

6.5 Further cohort analysis.--The cohort analysis is a useful tool for understanding the dynamics of the albacore population of the North Pacific Ocean, but is demanding in data and assumptions. Sensitivity analysis, or analysis of the behavior of the model outputs to changes in assumptions, has not been done and the participants recommended that such analyses be completed. The use of different growth rates and a refined method of estimating appropriate F vectors employing tagging data should be studied.

6.6 Indexing recruitment and stock fecundity.--The cohort analysis suggests that for the 1949-62 year classes variation in recruitment was as high as fourfold or fivefold, and had a major impact on fluctuations in the total yield. The participants therefore felt that recruitment variation or more specifically the stock-recruitment relationship for North Pacific albacore should receive more research emphasis. It was recommended that as an initial effort the spawning biomass estimates in NPALB/75/3 should be refined with fecundity indices and sex ratio information. The participants also felt that more refined measures of nominal CPUE by age groups from particularly the Kuroshio front fishing area should be collected because the changes in the catch rates of the young fish caught in that area might be useful as indices of recruitment strength and future yields.

6.7 Impact of environmental factors.--Environmental factors influence albacore behavior, availability, and abundance which in turn determine fishing success. The participants felt that the effects of environmental factors on measures of apparent abundance should be studied.

6.8 Socio-economic considerations in interpretation of data.--Socio-economic factors such as strikes or price disputes may materially affect fisheries data and should be considered wherever possible in interpretation of historic as well as current statistics.

6.9 Problems in measuring effective fishing effort.--It was pointed out that the North Pacific albacore fisheries are all multi-species fisheries. Nominal fishing effort for the United States troll fishery is easily separated into effort directed to albacore, and procedures are available for adjusting nominal effort of the Japanese longline fishery for effort directed to albacore only. For the Japanese pole-and-line fishery that exploits both skipjack tuna and albacore, nominal effort is probably underestimating effective effort, primarily because only days with successful catches are tabulated. The participants recommended that further work be done to better estimate effective effort as directed to albacore.

7. Future Activities

It was suggested that the Southwest Fisheries Center and the Far Seas Fisheries Research Laboratory develop specific objectives and a timetable for further joint research, drawing chiefly on the recommendations outlined in this report. It was further suggested that results of the next phase of investigation be reviewed in about 1 year, preferably in Japan. At this second workshop, invitation of participants from other countries exploiting the North Pacific albacore stock should be considered.

Appendix A

LIST OF PARTICIPANTS

National Marine Fisheries Service

R. Michael Laurs
Tamio Otsu
Gary T. Sakagawa
Richard S. Shomura
Robert A. Skillman
Jerry A. Wetherall
Marian Y. Y. Yong

Far Seas Fisheries Research Laboratory

Toshio Shiohama

California Department of Fish and Game

Harold B. Clemens
Charles H. Hooker

Oregon Department of Fish and Wildlife

Larry H. Hreha

Washington Department of Fisheries

Richard Lincoln
Mark Pedersen

Others

John Harville, Pacific Marine Fisheries Commission
Alex Rawung, Marine Fisheries Research Institute, Jakarta, Indonesia
Minato Yasui, Tokai University, Shimizu, Japan

Appendix B

AGENDA

A. Preliminaries

1. Welcome by Richard S. Shomura, Director, Honolulu Laboratory

2. Appointment of workshop chairman and rapporteurs

3. Discussion and adoption of agenda

B. Recent status of Japanese North Pacific albacore fisheries and trends in albacore consumption

Mr. Toshio Shiohama
Far Seas Fisheries Research Laboratory, Shimizu

C. Assessments of the North Pacific albacore stock

1. General review of stock assessment approaches, objectives, and assumptions

Dr. Jerry A. Wetherall
National Marine Fisheries Service, Honolulu

2. Preliminary assessment of the North Pacific albacore stock by the analysis of catch and effort statistics

Mr. Toshio Shiohama
Far Seas Fisheries Research Laboratory

3. Cohort analysis of the albacore stock and assessment of yield per recruit

Dr. Jerry A. Wetherall
National Marine Fisheries Service

4. Summary and synthesis of stock assessments

D. Critical problems in stock assessment and specific recommendations for further cooperative research by the National Marine Fisheries Service and the Far Seas Fisheries Research Laboratory

E. Discussion of areas for further cooperation between National Marine Fisheries Service and state fishery agencies

F. Drafting of workshop report

G. Adoption of report and closing of workshop

Appendix C

LIST OF BACKGROUND DOCUMENTS

NPALB/75/1 Shiohama, T. 1975. Recent status of the Japanese North Pacific albacore fishery and changing trends in albacore consumption. (Translated from the Japanese by Tamio Otsu, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii.)

NPALB/75/2 Shiohama, T., and Shou Morita. 1975. Assessment of North Pacific albacore stock (preliminary).

NPALB/75/3 Wetherall, J. A., and M. Y. Y. Yong. 1975. A cohort analysis of the North Pacific albacore stock and an assessment of yield per recruit in the American and Japanese fisheries.

NPALB/75/4 Wetherall, J. A., and M. Y. Y. Yong. 1975. A cohort analysis of the North Pacific albacore stock and an assessment of yield per recruit in the American and Japanese fisheries. Appendix on sustainable yields.

Southwest Fisheries Center Administrative Report No. 4H, 1976

MAY 10 1977

A SUMMARY OF ENVIRONMENTAL AND TUNA FISHING INFORMATION OF THE LINE ISLANDS

Richard N. Uchida[1]

March 1976

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

CONTENTS

Introduction 1

Description of the islands 2

Kingman Reef. 3

Palmyra Island. 4

Washington Island 4

Fanning Island. 6

Christmas Island. 7

Jarvis Island 9

Malden Island 10

Starbuck Island 11

Caroline Island 11

Vostok Island 12

Flint Island. 13

Climate. 14

Temperature 15

Wind speed and direction. 15

Rainfall. 19

Climate at Christmas Island 21

Rainfall 22

Temperature. 23

Atmospheric pressure 23

Relative humidity. 23

Cloud. 24

Sunshine. 24

Wind. 24

Oceanographic climate 25

Temperature. 25

Surface currents 29

Upwelling. 31

Equatorial undercurrent. 32

Plankton. 33

Tuna resource 36

Bird flock and fish school sightings 37

Tuna fishing trials. 39

Pole-and-line fishing 40

Purse seining 44

Trolling. 46

Longline fishing. 51

Size of fish 57

Literature cited. 61

Appendix

LIST OF TABLES

Table 1.--Minimum time and fetch required for winds to produce waves of a given height, and length of the resulting waves (adapted from McGary and Naito 1957 by BCF 1963).

Table 2.--Surface wind summaries for years with extreme rainfall at Malden Island (from Seelye 1950).

Table 3.--The average annual rainfall, its variability, and the percentage frequency of dry months at Fanning and Malden Islands (from Seeyle 1950).

Table 4.--Mean, highest and lowest monthly and annual rainfall for the period 1903-66 at London, Christmas Island, in millimeters (from Jenkin and Foale 1968).

Table 5.--Summary of monthly temperature data for London, Christmas Island 1953-65 in °C and °F (from Jenkin and Foale 1968).

Table 6.--Average mean monthly and annual atmospheric pressure at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in millibars (from Jenkin and Foale 1968).

Table 7.--Average mean monthly and annual relative humidity at 0800, 1400, and 2000 h (local time) and for the whole day at London, Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Table 8.--Average mean monthly and annual cloud cover at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in oktas and tenths (from Jenkin and Foale 1968).

Table 9.--Mean monthly sunshine in hours per day at London, Christmas Island (from Jenkin and Foale 1968).

Table 10.--Mean monthly and annual wind speed at 0800, 1400, and 2000 h (local time) and for the whole day in meters per second (m/s) and knots (kn) at Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Table 11.--Average volumes and night-day ratios of zooplankton collected by Clarke-Bumpus samplers on Hugh M. Smith cruise 16 for three depths of sampling, July-August 1952 (from Hida and King 1955).

Table 12.--Summary of island observations on fish schools and bird flocks, 1950-53 (from Murphy and Ikehara 1955).

Table 13.--Summary of semioceanic observations associated with particular island groups, 1950-53 (from Murphy and Ikehara 1955).

Table 14.--Total scouting hours and rate of sighting of bird flocks, skipjack tuna schools, and total schools in the 5° square bounded by lat. 0° and 5°N and by long. 155° and 160°W (data extracted from Naughton, see footnote 5).

Table 15.--Results of baiting operations in the Line Islands (data extracted from Table 1, Ikehara 1953).

Table 16.--Summary of baiting operations in the Line Islands, 1955-64.

Table 17.--Summary of bait survey, Charles H. Gilbert cruise 19.

Table 18.--Summary of the results of live-bait fishing for tunas in the Line Islands (data extracted from Table 2, Ikehara 1953).

Table 19.--Daily troll catches in the Line Islands, John R. Manning cruise 2, 1950 (from Bates 1950).

Table 20.--Observations on five large schools of tuna sighted at Kingman Reef on John R. Manning cruise 2, 1950 (from Bates 1950).

Table 21.--Number of yellowfin tuna caught by 2-h periods, *John R. Manning* cruise 2, 1950 (from Bates 1950).

Table 22.--Results of trolling in island areas, 1950-53 (from Murphy and Ikehara 1955).

Table 23.--Results of trolling in the Line Islands (from Iversen and Yoshida 1957).

Table 24.--Species of fish listed by Murphy and Shomura (1972) as likely to be captured by trolling or observed near the surface in the central equatorial Pacific Ocean (from Helfrich 1973).

Table 25.--Number of tuna, marlin, shark, and other species caught on longline gear on exploratory fishing cruises to the central equatorial Pacific Ocean, 1950-56.

LIST OF FIGURES

Figure 1.--The location of the Line Islands in the central equatorial Pacific Ocean.

Figure 2.--Kingman Reef (from Bates 1950).

Figure 3.--Palmyra Island (from Bates 1950).

Figure 4.--Washington Island (from Bates 1950).

Figure 5.--Fanning Island (from Bates 1950).

Figure 6.--Christmas Island (from Bates 1950).

Figure 7.--Jarvis Island (from H. O. 1198, 11th ed., Sept. 1945).

Figure 8.--Malden Island (from H. O. 1980, 9th ed., Mar. 1948).

Figure 9.--Starbuck Island (from H. O. 1980, 9th ed., Mar. 1948).

Figure 10.--Caroline Island (from H. O. 1980, 9th ed., Mar. 1948).

Figure 11.--Vostok Island (from H. O. 1980, 9th ed., Mar. 1948).

Figure 12.--Flint Island (from H. O. 1980, 9th ed., Mar. 1948).

Figure 13.--January winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 14.--April winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 15.--July winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 16.--October winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 17.--Average wind velocities, December-February, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 18.--Average wind velocities, March-May, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 19.--Average wind velocities, June-August, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 20.--Average wind velocities, September-November, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

Figure 21.--Average annual rainfall in inches (from Seelye 1950).

Figure 22.--Location of wet and dry islands in the central equatorial Pacific Ocean (from Bryan 1941).

Figure 23.--Average monthly and annual rainfall for Palmyra, Washington, Fanning, Christmas, Malden, and Canton Islands (from Austin 1954b).

Figure 24.--Month of highest average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

Figure 25.--Month of least average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

Figure 26.--Bi-monthly averages of sea-surface temperatures at Christmas Island (Barkley 1962, see footnote 3).

Figure 27a.--Surface temperature in the central equatorial Pacific Ocean in January (from U.S. Navy Hydrographic Office 1944).

Figure 27b.--Surface temperature in the central equatorial Pacific Ocean in February (from U.S. Navy Hydrographic Office 1944).

Figure 27c.--Surface temperature in the central equatorial Pacific Ocean in March (from U.S. Navy Hydrographic Office 1944).

Figure 27d.--Surface temperature in the central equatorial Pacific Ocean in April (from U.S. Navy Hydrographic Office 1944).

Figure 27e.--Surface temperature in the central equatorial Pacific Ocean in May (from U.S. Navy Hydrographic Office 1944).

Figure 27f.--Surface temperature in the central equatorial Pacific Ocean in June (from U.S. Navy Hydrographic Office 1944).

Figure 27g.--Surface temperature in the central equatorial Pacific Ocean in July (from U.S. Navy Hydrographic Office 1944).

Figure 27h.--Surface temperature in the central equatorial Pacific Ocean in August (from U.S. Navy Hydrographic Office 1944).

Figure 27i.--Surface temperature in the central equatorial Pacific Ocean in September (from U.S. Navy Hydrographic Office 1944).

Figure 27j.--Surface temperature in the central equatorial Pacific Ocean in October (from U.S. Navy Hydrographic Office 1944).

Figure 27k.--Surface temperature in the central equatorial Pacific Ocean in November (from U.S. Navy Hydrographic Office 1944).

Figure 27ℓ.--Surface temperature in the central equatorial Pacific Ocean in December (from U.S. Navy Hydrographic Office 1944).

Figure 28.--Summary of various oceanographic and biological data, August-October 1951. Hugh M. Smith cruise 11, Northbound section, panels (A) through (F), southbound section panel (G) (from Austin 1954a).

Figure 29.--Schematic representation of the major surface currents and surface isotherms in the central and eastern equatorial Pacific. The area most intensively surveyed is shaded. Arrows denote approximate current direction (adapted from Schott 1935 by Murphy and Shomura 1972).

Figure 30.--Meridional temperature sections, based on average values in areas of 2° of latitude by 10° of longitude (from Barkley 1962, see footnote 3).

Figure 31.--Surface temperature and variation in phosphate (indicated by shading) in the central equatorial Pacific Ocean (Sette and staff 1954).

Figure 32.--Depth of the thermocline as determined from the BT data, September-December 1955. The shaded section is the region where thermocline depth could not be determined objectively, because the BT trace showed either more than one inflection or a continuous negative gradient from the surface to the maximum depth of the trace (from Austin 1960).

Figure 33.--Above, surface temperature and below, temperature section based on BT data along long. 158°W, 15-26 January 1951. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. Hugh M. Smith cruise 8 (from Cromwell 1954).

Figure 34.--Above, surface temperature and below, temperature section based on BT data along long. 158°W, 28 July-6 August 1950. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. Hugh M. Smith cruise 5 (from Cromwell 1954).

Figure 35.--Typical BT traces for various regions crossed during Hugh M. Smith cruise 11, August-September 1951 (from Austin 1954a).

Figure 36.--Vertical temperature (°F) distribution along the equator illustrating the east-west slope of the thermocline, September-December 1955 (from Austin 1960).

Figure 37a.--Surface drift vectors for January (from U.S. Navy Hydrographic Office 1950).

Figure 37b.--Surface drift vectors for February (from U.S. Navy Hydrographic Office 1950).

Figure 37c.--Surface drift vectors for March (from U.S. Navy Hydrographic Office 1950).

Figure 37d.--Surface drift vectors for April (from U.S. Navy Hydrographic Office 1950).

Figure 37e.--Surface drift vectors for May (from U.S. Navy Hydrographic Office 1950).

Figure 37f.--Surface drift vectors for June (from U.S. Navy Hydrographic Office 1950).

Figure 37g.--Surface drift vectors for July (from U.S. Navy Hydrographic Office 1950).

Figure 37h.--Surface drift vectors for August (from U.S. Navy Hydrographic Office 1950).

Figure 37i.--Surface drift vectors for September (from U.S. Navy Hydrographic Office 1950).

Figure 37j.--Surface drift vectors for October (from U.S. Navy Hydrographic Office 1950).

Figure 37k.--Surface drift vectors for November (from U.S. Navy Hydrographic Office 1950).

Figure 37ℓ.--Surface drift vectors for December (from U.S. Navy Hydrographic Office 1950).

Figure 38.--Schematic view of the equatorial current system incorporating recent empirical determinations of flow north of the equator. Flow south of the equator is indicated as questionable (from Murphy and Shomura 1972).

Figure 39.--Directions of current transport (solid arrows) which would exist near the equator under various wind conditions if there were no pressure-gradient force acting. The current magnitude is drawn everywhere constant (solid arrows). For each wind condition the meridional components of the current transport (dotted arrows) are drawn to emphasize the regions of meridional divergence (Div.) and convergence (Conv.) (from Cromwell 1953).

Figure 40.--Schematic representation of circulation in the meridional plane near the equator during a southeast wind when front is present (below). The arrows have the character of streamlines and do not represent trajectories. The arrow shaft lengths indicate roughly the relative magnitudes of flow. Small circles indicate regions of slight and variable flow in this plane. The shaded zone in the upper diagram represents an equatorial front (Cromwell 1953).

Figure 41.--Concept of equatorial circulation along long. 150°W. The surface currents are shown by broad arrows; the vertical temperature structure by the fine lines of equal temperature (from Sette and staff 1954).

Figure 42.--Variations in temperature, salinity, oxygen, inorganic phosphate, thermocline depth, and zooplankton volume along long. 158° and 172°W as found on Hugh M. Smith cruise 5, June-August 1950 (from King and Demond 1953).

Figure 43.--Left: Zooplankton data from 11 crossings of the equatorial currents between long. 140°W and 180°, combined grossly without regard for longitude or season. The number of observations included in the averaging for each degree of latitude appear at the right. Middle and right: Zooplankton data concurrent with the hydrographic sections examined by Cromwell (1953).

Figure 44.--Variation with the current system in (A) zooplankton volumes (adjusted) and (B) yellowfin tuna longline catch for the two 6-month periods, January-June, a period with northeast or light and variable winds, and July-December, a period of prevailing southeast trade winds (in the central equatorial Pacific Ocean) (from King and Hida 1957).

Figure 45.--Relation of an oceanographic front to the distribution of zooplankton (adjusted volumes) as demonstrated by three series of stations along long. 172°, 158°, and 120°W of Hugh M. Smith cruises 2, 5, and 18, respectively (from King and Hida 1957).

Figure 46.--Longitudinal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent, at about lat. 5°N to 5°S, with the data segregated by 10° intervals of longitude (from King and Hida 1957).

Figure 47.--Seasonal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent at about lat. 5°N to 5°S, with the data segregated into quarterly periods of 3 months each (from King and Hida 1957).

Figure 48.--Wind, plankton, and tuna distribution in the equatorial zone. A. Resultant wind vectors were computed as the weighted means of frequency and speed from the several compass points for 5° squares bordering the equator as published in the U.S. Hydrographic Office Pilot Chart for the North Pacific for August 1952; the arrows point in the direction of travel and their shafts are proportional to the weighted mean speed. B. Mean plankton volumes at several longitudes were computed as the mean of all hauls taken between lat. 5°S and 10°N at or near the given longitude. C. Distribution of yellowfin tuna in the mid-Pacific equatorial region is estimated from longline catches. The light stippling in the POFI area represents less than three yellowfin tuna per hundred hooks, the heaviest represents more than nine per hundred hooks, and the intermediate stippling represents intermediate catching rates. For orientation as to location and area, the extensive band of light stippling represents the area of the Japanese prewar longline fishery; the dashed outline shows

the area of the American west coast live bait and purse seine fishery for yellowfin tuna and skipjack tuna. Since preparation of the above chart, a line of fishing stations along long. 110°W has proved the continuity of the band of yellowfin tuna across the "unexplored area" (from Sette 1955).

Figure 49.--Seasonal distribution of tuna school sightings in the Line, Phoenix, and Hawaiian Islands. Total fish schools per day include unidentified schools as well as yellowfin tuna and skipjack tuna. The numbers, such as 0/32, indicate that no schools were seen in 32 days of scouting (from Murphy and Ikehara 1955).

Figure 50a.--Bird flock sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

Figure 50b.--Bird flock sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

Figure 50c.--Bird flock sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

Figure 50d.--Bird flock sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

Figure 50e.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

Figure 50f.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

Figure 50g.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

Figure 50h.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

Figure 50i.--Total school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

Figure 50j.--Total school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

Figure 50k.--Total school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

Figure 50ℓ.--Total school sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

Figure 51.--Bait resources in the central Pacific islands (from Sette and staff 1954).

Figure 52.--Yellowfin tuna troll catch rates in the Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

Figure 53.--Yellowfin tuna troll catch rates in the Line Islands 1955-56 arranged by time of day, (data on total number of hours trolled given in parentheses) (from Iversen and Yoshida 1957).

Figure 54.--Relationship of yellowfin tuna troll catch rates to areas, Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

Figure 55.--Catches of tuna by Hugh M. Smith cruises 5, 7, and 11, 1950-51. The bar graphs represent tuna catch rates, yellowfin tuna shown in black, other tunas in white (from Murphy and Shomura 1953a).

Figure 56.--Relationship between surface temperature and phosphate, zooplankton volume, and yellowfin tuna catch at several longitudes for the zone lying between lat. 1° and 5°N (from Murphy and Shomura 1972).

Figure 57.--The distribution of deep-swimming yellowfin tuna (top), bigeye tuna (middle), and albacore (bottom) in the central equatorial Pacific Ocean. The isograms are in units of number of fish caught per 100 hooks (from Murphy and Shomura 1972).

Figure 58.--Percentage of Cavalieri's longline-caught tuna acceptable for canning (from Sette and staff 1954).

Figure 59.--Surface temperatures at Christmas Island and Line Islands yellowfin tuna catches during 1954 by 5-day periods (from Iversen and Yoshida 1956).

Figure 60.--Daily yellowfin tuna longline catch rates in the Line Islands, 1955-56 (from Iversen and Yoshida 1957).

Figure 61.--Length frequencies (fork lengths) of the principal tuna species taken in the central equatorial Pacific by type of gear (from Murphy and Shomura 1972).

Figure 62.--Length-weight frequency distribution of yellowfin tuna caught by surface trolling in the Line Islands, 1950 (from Bates 1950).

Figure 63.--Length-frequency distributions of oceanic and insular yellowfin tuna caught by longlining and trolling, January 1955 to February 1956 (from Iversen and Yoshida 1957).

Figure 64.--Yellowfin tuna size distribution with distance from land, January-December 1953 (from Shomura and Murphy 1955).

Figure 65.--Mean lengths of samples of longline-caught yellowfin tuna plotted against longitude of capture, August-November 1952 (from Murphy and Shomura 1955).

Figure 66.--Mean lengths of samples of longline-caught bigeye tuna plotted against the longitude of capture, August-November 1952 (from Murphy and Shomura 1955).

Figure 67.--Size distribution of skipjack tuna taken by longline in the central equatorial Pacific, 1953 (from Shomura and Murphy 1955).

ABSTRACT

This paper provides a brief historical resumé and description of the Line Islands and reviews much of the published information available on the climate, oceanographic climate, planktonic surveys, and tuna resource in that region. Of significance is the delineation of a major fishing ground for deep-swimming tunas in the central equatorial Pacific. Attention is focused on tuna fishing trials by several types of gear and the results obtained. Change in abundance of tuna as a function of the variation in the wind-driven ocean circulation in that region is also discussed.

INTRODUCTION

The fishery for tropical tunas in the eastern Pacific Ocean began in California prior to World War I as an outgrowth of the albacore, *Thunnus alalunga*, fishery, which started about 1903. The eastern Pacific is one of the major tuna producing areas of the world, where two species of tuna--yellowfin, *T. albacares*, and skipjack, *Katsuwonus pelamis*, are fished intensively by nationals of South, Central, and North America. Because of heavy exploitation, the yellowfin tuna fishery in the eastern Pacific has been under international management since 1966 (Joseph and Calkins 1969). However, it has not been demonstrated that there is a need to implement measures to conserve the other species of tunas in the eastern Pacific.

The demand for canned tuna continues to increase and the eastern Pacific tuna fishing fleet continues to grow. But it is obvious that little increased production can be expected from yellowfin tuna there. The eastern Pacific fleet must supplement its yellowfin tuna catch by fishing on tuna stocks capable of sustaining greater fishing pressure than is now being imposed on them. Among the possibilities are yellowfin tuna stocks outside the regulated area, and the bluefin tuna, *T. thynnus*, and skipjack tuna stocks throughout the Pacific.

It is reasonable to expect, therefore, that the eastern Pacific fleet will intensify their fishing effort in areas outside the Commission's Yellowfin Regulatory Area (CYRA). Among the areas now being considered is the Line Islands. For this reason, it is appropriate to bring together in summary form, for the benefit of the fishing industry, such information, published or unpublished, as may be useful in planning future fishing ventures to the Line Islands.

DESCRIPTION OF THE ISLANDS

Fig. 1 The Line Islands, shown in Figure 1, are small, low, semi-barren coral atolls that run south by southeast on both sides of the equator between long. 150° and 163°W north of the Society and Cook Islands (Tudor 1972). Extending from Kingman Reef, which lies about 925 nautical miles south by west of Honolulu at about lat. 6°N, to Flint at lat. 11°26'S, the 11 islands of the Line group straddle the equator.

Five islands in the group are usually identified as the northern Line Islands. These are Kingman Reef and Palmyra Island, both belonging to the United States, Washington and Fanning Islands, attached to the British Colony of Gilbert and Ellice Islands, and Christmas Island, which is formally a condominium jointly claimed by the United States and the United Kingdom.

Among the southern Line Islands, Jarvis Island belongs to the United States, whereas Malden, Starbuck, Caroline, Vostok, and Flint Islands are British possessions administered directly by the High Commissioner for the Western Pacific.

Palmyra, Fanning, Christmas, and Caroline have lagoons; the remaining seven have the familiar fringing reef. Christmas Island has an open saltwater lagoon and many ponds of varying salinity. All the islands in the group are either privately or government-owned; therefore, fishing vessels would require permission to land or fish in the islands' coastal waters.

KINGMAN REEF

. 2 This bare, triangular reef, shown in Figure 2, measures
tnote 2 roughly 14 km (9 statute miles[2]) long and 8 km (5 mi) wide and encloses a deep lagoon. It is at the northern end of the Line Islands group at lat. 6°24'N and long. 162°24'W (Tudor 1972). The reef, located 1,714 km (925 mi) south of Honolulu, was discovered in 1798 and annexed by the U.S. in May 1922. Between 1934 and 1938, the sheltered lagoon at Kingman Reef served as a half-way station for flying boats on airmail service between Honolulu and Pago Pago, American Samoa. Kingman Reef is still under the control of the U.S. Department of Navy but there is no active military installation. The reef covers an area of about 0.3 sq km (0.1 sq mi) (Bryan 1951).

PALMYRA ISLAND

Fig. 3 Discovered in 1802, Palmyra Island (Fig. 3) is located 61 km (33 mi) southeastward of Kingman Reef at lat. 5°52'N and long. 162°06'W (Tudor 1972). Palmyra was formerly a part of the Hawaiian Islands but was excluded from the boundaries of Hawaii by the Hawaii Statehood Act and is now the responsibility of the U.S. Department of the Interior. Palmyra consists of about 50 islets totaling about 6 sq km (1,470 ac) of land. The main harbor is in West Lagoon, which is entered by a channel on the southwest side of the atoll; both channel and harbor will accommodate vessels drawing about 4 m (13 ft). Roads and causeways built during World War II, when the U.S. Navy had 6,000 men stationed there, are run down and overgrown with vegetation.

The atoll is only about 2 m (6 ft) above sea level. As a result of a high annual rainfall, the island is wet and humid and covered by dense vegetation. There are, however, many clear, sunny days (Bryan 1941).

WASHINGTON ISLAND

Fig. 4 Washington Island (Fig. 4), discovered in 1798 and annexed by Great Britain in 1889, lies 222 km (120 mi) southeast of Palmyra at lat. 4°43'N and long. 160°25'W (Tudor 1972). The atoll, about 5.5 km (3.4 mi) long by 1.9 km (1.2 mi) at its greatest width, has a circumference of about 14.5 km (9 mi) and a land area of less than 10.4 sq km (4 sq mi) (Bryan 1941). The land is covered with a dense growth of

coconut palms and underbrush. Most of the beach is of fine sand and the fringing reef in most places is not more than 183 m (200 yd).

The atoll is included in the Gilbert Islands Colony. According to Tudor (1972), the land is all owned by Fanning Island Plantations Ltd.; about 78 Gilbertese are employed in copra production. There is an anchorage at the west point of the island. Bryan (1941) reported that the bank off the west point has an area of about 5 sq km (2 sq mi) with depths between 9 and 36 m (5 and 20 fm). Vessels may anchor on this bank but only in calm weather. A new landing located on the south side about 0.8 km (0.5 mi) from the southwest point is reportedly a better anchorage.

A distinctive feature of Washington Island is the freshwater lagoon on the eastern half of the island (Bryan 1941). The western half has two peat bogs that occupy the former lagoon, as evidenced by the presence of marine shells and white coral sand on the lagoon bottom and beneath the layers of peat.

The lagoon, about 2.8 km (1.5 mi) long by 1.3 km (0.7 mi) wide, is 1 m (3 ft) above sea level and averages 1.5 m (5 ft) deep although it is reported to reach a depth of 9 m (30 ft) in some places (Bryan 1941). The water level in the lagoon is maintained by rainfall, which on Washington is heavier than on Fanning Island. The climate at Washington is much the same as that at Fanning where high temperatures are tempered to some extent by the trade winds.

FANNING ISLAND

Fanning Island (Fig. 5), forms the Line Islands Administrative District together with Washington and Christmas islands (Tudor 1972). Chave (1971) describes it as a beautiful atoll located at lat. 3°55'N, long. 159°23'W, approximately 139 km (75 mi) southeast of Washington Island. The island has a circumference of about 51 km (32 mi) and has a land area of about 32.5 sq km (12.5 sq mi). Composed of three islets enclosing a shallow lagoon, the atoll is 19 km (12 mi) long and 10 km (6 mi) wide.

British Cable and Wireless established a cable station on Fanning in 1902 to serve as a connecting link of the Pacific cable between British Columbia and Suva, Fiji Island, but abandoned it in 1963. In 1966, the University of Hawaii, Honolulu, Hawaii, acquired a lease from the former Gilbert and Ellice Islands Colony for the abandoned cable station land and its 15 buildings (Chave 1971). A 760-m (2,500-ft) airstrip has since been added to the island by the University.

All the land on the island is owned by Fanning Island Plantation Ltd., a subsidiary of Burns, Philp and Company, Ltd., Sydney, Australia. About 12.5 sq km (3,100 ac) of the total land area are under cultivation for copra production. The island is inhabited by 600 Gilbertese copra workers.

English Harbor provides sheltered anchorage for vessels up to 1,000 tons. However, the lagoon entrance channel at English Harbor is subject to strong tidal currents, with speeds up to 7 knots (13 km/h). Effects of this current can be felt as far as a mile offshore, particularly on the outflowing ebb tide. Passage through the channel should only be attempted at slack periods in the tidal cycle. Another calm weather port is at Whaler's Anchorage.

CHRISTMAS ISLAND

Situated 284 km (153 mi) southeast of Fanning Island at lat. 1°55'N and long. 157°20'W, Christmas Island (Fig. 6) is the largest coral atoll in the world (Jenkin and Foale 1968). The atoll, which covers 640 sq km (247 sq mi) of which 321 sq km (124 sq mi) is land, is 2,474 km (1,335 mi) south of Honolulu. The greatest length is 53 km (33 mi) from north of Northwest Point to Southeast Point; the maximum southwest-northeast distance is 31 km (19 mi). Christmas Island is shaped like a lobster claw whose jaws open to the northwest. Within the claws is a semicircular lagoon which occupies 160 sq km (62 sq mi). The lagoon is shallow, and has numerous coral heads; it should only be entered by small boat, preferably with the assistance of someone with local knowledge.

The island was discovered in 1777 by Captain James Cook, annexed by Great Britain in 1888, and included in the former colony of the Gilbert and Ellice Islands in 1919 (Tudor 1972). British control of the island was disputed by the United States in 1936-38, and although recognizing that Christmas Island is presently administered by the Gilbert Islands Colony, the United States has not relinquished its claim on the island.

There are two settlements on the island, London and Paris, but the latter is deserted and in ruins. These settlements are located to the north and south of the entrance channel to the main lagoon, respectively. A third settlement, called Poland, located near the Southwest Point, has been permanently occupied since June 1966.

In addition to the lagoon, Christmas Island has about 500 lakes with salinities varying widely between 35°/₀₀ and 330°/₀₀. At present, the Christmas Island Plantation, which is government-owned and operated, has 20 sq km (5,000 ac) under cultivation for copra production. The island has an excellent network of paved main roads and hardpan secondary roads. A 1,800-m (6,000-ft) runway is at the northern end of the island.

JARVIS ISLAND

Lying 371 km (200 mi) southwest of Christmas Island and a little more than 41 km (22 mi) south of the equator is Jarvis Island (Fig. 7) at lat. 0°22'S and long. 160°03'W (Bryan 1941). This atoll, which is small, low, and basin shaped, measures 2.9 km (1.8 mi) long by 1.6 km (1 mi) at its greatest width (Bryan 1941). Discovered in 1821, it wasn't until 1857 that the American Guano Company claimed the island and started removing large quantities of guano (Tudor 1972). Jarvis was abandoned in 1879. Annexed by Great Britain in 1889, the island was leased to the Pacific Phosphate Company but apparently never worked. The United States claimed the island in 1935 with no objection from Britain. The island has been used since then as a weather station; a settlement on the west side, called Millersville, consisted of some stone and wooden houses and a radio shack. Now under control of the Department of the Interior, the island was most recently occupied during the International Geophysical Year (1957-58).

The highest point around the rim of the island is 7 m (23 ft) and portions of the east rim are less than 3.6 m (12 ft) (Bryan 1941). The rim is narrow and encloses an extensive basin; however, there is no permanent lagoon. A narrow fringing reef, roughly 90 m (100 yd) wide, surrounds the steep beach. On the west side is a narrow channel blasted through the reef. This makes landing comparatively easy.

MALDEN ISLAND

Fig. 8

British-owned Malden Island (Fig. 8), located at lat. 4°03'S and long. 154°59'W, lies 446 km (241 mi) south of the equator and 691 km (373 mi) southeast of Jarvis (Bryan 1941). It is a triangular, flat coral island measuring about 8 km (5 mi) long by 6 km (4 mi) wide and the east central portion is occupied by a very large saltwater lagoon. The land area is given as 43 sq km (10,700 ac) with an additional 36 sq km (9,000 ac) of lagoon.

The ridge that encloses the lagoon is nowhere more than 8 to 9 m high (25 to 30 ft) (Bryan 1941). The shore is surrounded by a narrow fringing reef with the greatest width variously estimated between 180 and 550 m (200 and 600 yd). A steep beach rises from the reef. The anchorage is precarious because of deep water off the edge of the reef. Despite the existence of a small pier near the south end of the west shore, landing on the island is often difficult.

Malden is somewhat barren with only stunted vegetation growing there (Tudor 1972). At the time of its discovery in 1825 about 40 stone archeological ruins were found on the island. Subsequent discovery of guano deposits on the island in 1840 led an influx of several Australian guano companies over the years who worked the island profitably for 70 years. The island has been unused and unoccupied since 1927.

Malden is warm, but the climate is pleasant despite its uniformity (Bryan 1941). Temperature varies between 24° and 37°C (75° and 99°F) and averages 29°C (85°F). Violent storms are rare.

STARBUCK ISLAND

Situated at lat. 5°37'S and long. 155°53'W, Starbuck Island
ig. 9 (Fig. 9) is 200 km (108 mi) south by southwest of Malden Island and 623 km (336 mi) south of the equator (Bryan 1941). Starbuck is a low, flat, coral atoll about 8.8 km (5.5 mi) long and 3.7 km (2.3 mi) wide. It is barren and without any palms. The greatest height along the beach crest is about 4.5 m (14 ft); within the crest the island is depressed with small, shallow saltwater lagoons near the eastern end. Land area is about 2.6 sq km (1 sq mi).

The island, discovered in 1823 and worked for guano for many years beginning in 1870, has been unoccupied and unworked since 1920 (Tudor 1972). At present, Starbuck is a British possession.

The steep beach of Starbuck Island is surrounded by a fringing reef which is about 914 m (1,000 yd) wide (Bryan 1941). There is no safe anchorage. A break has been blasted in the reef near the West Point, but landing is difficult and often dangerous.

CAROLINE ISLAND

ig. 10 Caroline Island (Fig. 10), a small atoll measuring 9.6 km (6 mi) long and less than 1.6 km (1 mi) wide, lies 778 km (420 mi) southeast of Starbuck Island and 1,104 km (596 mi) south of the equator (Bryan 1941; Tudor 1972). This British-owned atoll, located at lat. 9°58'S and long. 150°13'W, has more than 20 islets strung along a reef, which encloses a shallow lagoon. There is no passage through the connecting reef.

Some of the islets are 5-6 m (15-20 ft) high and most are covered with groves of coconut palms and underbrush (Bryan 1941).

The reef, which extends for about 1.6 km (1 mi) off the southwest and southeast points, is not exposed at low water (Bryan 1941). On the side of the island that is exposed to the weather, the sea breaks heavily. There is no anchorage, but landings can be made at high water through a narrow break in the reef off the northwest point of the southern islet; at low water, one must wade across the reef in knee-deep water.

Caroline Island, discovered in 1795, was once inhabited by Polynesians and there was a settlement of about 30 people on the southern islet in 1868 (Tudor 1972). Native temple platforms and graves containing adzes have been found on the two northern islets (Bryan 1941). Water can be found by digging. The climate is warm but pleasant with temperatures rather uniform. During much of the year, the island is under the influence of the southeast trades. Showers may be sudden particularly at night.

VOSTOK ISLAND

Located at lat. 10°06'S and long. 152°23'W, Vostok Island (Fig. 11) is a low, uninhabited triangular atoll approximately 232 km (125 mi) west of Caroline Island and 1,121 km (605 mi) south of the equator (Bryan 1941). The island is distinguished only by a dense central clump of buka trees (Pisonia), which reach a height of about

Fig. 11

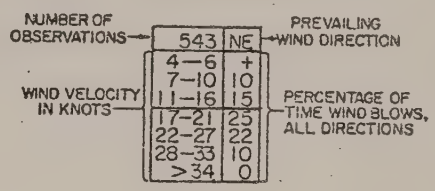
25 m (80 ft) above sea level. According to Bryan (1941), this type of vegetation is very distinctive; the canopy is so dense that no other plants will grow beneath the buka trees. Because of decaying leaves and branches, the soil is rich in humus and usually damp around the bases of the soft, massive tree trunks.

Vostok is about 1.3 km (0.8 mi) long, occupies an area less than 2.6 sq km (1 sq mi), and is completely surrounded by a platform reef which is 90 m (100 yd) or more wide and awash at low water (Bryan 1941). There is a boat passage through the reef at the southwest corner of the island but no anchorage (Tudor 1972). Discovered in 1820, Vostok was claimed by the United States under the Guano Act in 1856 but the claim was never pressed. Between 1873 and 1943, Vostok was worked sporadically for guano and copra. At present, the atoll is a British possession.

FLINT ISLAND

g. 12 Flint Island (Fig. 12) is a narrow island 4 km (2.5 mi) long and tapering toward both ends from a greatest width of 0.8 km (0.5 mi). It is located at the extreme southern end of the Line Island group at lat. 11°26'S and long. 151°48'W and is 1,270 km (685 mi) south of the equator and 159 km (86 mi) south by southeast of Vostok Island (Bryan 1941). This flat atoll is well wooded and is entirely surrounded by a narrow fringing reef which extends for nearly 1 km (0.6 mi) off the northern point of the island (Bryan 1941). A boat passage has been blasted through the reef leading to a landing place on the western side (Tudor 1972).

were made. The hatched block indicates Weather Ship Station November. The figure in the upper left in each set of data is the number of observations; the wind velocity ranges in knots are given below that. At the upper right, the prevailing wind direction is given. The percentages of time the winds, from whatever direction, are within the indicated velocity range are also given. For example:



In the figures, winds of 0-4 knots are omitted and wind frequencies of less than 0.5% are indicated by a plus sign (+). As a convenience for tuna fishing vessel operators, data on winds greater than 17 knots are set off by a line so that the proportion of time wind and sea conditions may seriously affect fishing operations can be quickly estimated.

The following descriptions of wind and sea conditions accompanying each figure (Figs. 13 to 16) were obtained from BCF (1963).

January winds (Fig. 13)

"Fresh to strong winds occur in several areas, mainly between latitudes 10° and 30°N. The area between Hawaii and longitude 130°W. experiences strong easterly and northeasterly winds about 30-40 percent of the time. The Tehuantepec region has experienced winds up to gale force about 30 percent of the time; gale-force winds (>34 knots) occur about 6 percent of the time. Other areas to the south of the Equator and westward have reported strong tradewinds (>16 knots) averaging about 20 percent of the time."

April winds (Fig. 14)

"Winds limiting fishing operations may be encountered in the Gulf of Tehuantepec about 6 percent of the time. Strong winds may also occur about 600-900 miles southeast of the Hawaiian Islands about 68 percent of the time. High easterly and southeasterly trade wind velocities also occur in the region of 0°-15°S. near 130°W.; here velocities in excess of 16 knots occur from 25-73 percent of the time."

July winds (Fig. 15)

"The maximum trade wind zones noted in April change very little, except for an eastward extension of strong winds to include the region near 10°S. and 110°W. Here easterly and southeasterly trades blow above 16 knots from 16-30 percent of the time. Increased easterly wind velocities are observed also in the Phoenix-Samoa-Tokelau Islands area."

October winds (Fig. 16)

"North winds exceed velocities of 16 knots about 24-25 percent of the time in the Tehuantepec region. Wind velocities from 17-27 knots prevail about 48 percent of the time in an area about 600-900 miles southeast of the Hawaiian Islands, and strong easterlies occur in an area from 5° to 15°S at 100° to 130°W. (east of the Marquesas) about 33-35 percent of the time."

Table 1 Sea conditions may be estimated from Table 1, which gives the maximum time and fetch required for winds to produce waves of a given height and the length of the resulting waves (BCF 1963). For example, a sustained wind of 20 knots blowing for a minimum of 19 h over a distance of 222 km (120 mi) will generate a 2.4-m (8-ft) sea with 47.2-m (155-ft) wave crest intervals.

Figs. 17-20 Figures 17 to 20, adapted from U.S. Weather Bureau (1938), Atlas of the Climatic Charts of the Oceans, show average wind velocities computed for the equatorial region, irrespective of direction (BCF 1963). In general, these figures show the shifting of the areas of maximum prevailing wind velocity by season. In winter (Fig. 17), the maxima occur in two distinct belts. One is at lat. 10°N and the other at about 10°S. Although the maximum spring trades persist in the northern hemisphere in a broad belt, there is a slackening of the maximum to the south of the equator except near long. 100° and 120°W (Fig. 18). Figure 19 shows that the summer winds increase south of the equator near long. 110°W, but to the north the northeast trades are diminished somewhat. By fall (Fig. 20), wind velocities are somewhat higher in the southern latitudes between long. 90° and 140°W.

Between the trade wind zones is an atmospheric low-pressure trough which is associated with rising warm moist air and weak variable winds. This zone is the doldrums, which marks the climatic equator. In January, the trough is near lat. 5°N at long. 150°W, at about the equator near long. 160°W, and near lat. 5°S at long. 170°W. But by July, it is farther north at about lat. 5°-9°N.

According to Seelye (1950), the percentage of east wind in the Line Islands area appears to be associated with the amount of
ble 2 rainfall. Table 2, which gives the surface wind summaries for 1914 and 1924, shows that at Malden Island the winds came from the east only 38% of the time in a year of extremely heavy rainfall. By contrast, in a year of extremely light rainfall, the wind blew out of the east 88% of the time.

RAINFALL

The variability of rainfall is the most significant feature of the climate in the Line Islands (Bryan 1941; Seelye 1950). It is governed largely by the location and strength of the doldrums (Barkley
otnote 3 1962).[3] In the northern Line Islands, rainfall is greater than the world's average, reaching 300 cm (118 in.) or more per year near lat. 5°N at long. 170°W and over 249 cm (98 in.) per year near lat. 5°N at long. 150°W. In the southern sections, the minimum rainfall of about 76 cm (30 in.) per year occurs near lat. 5°S at long. 150°W.

The average annual rainfall in the Line Islands region is shown in the map in Figure 21. Isohyets (line of equal rainfall) are drawn for 152, 229, and 305 cm (60, 90, and 120 in.). Areas with less than 152 cm (60 in.) are the dry zones; those with more than 305 cm (120 in.) are the wet zones. Bryan (1941) classified Kingman Reef, Palmyra, Washington, and Fanning Islands as wet (Fig. 22). The dry islands were Jarvis, Malden, and Starbuck Islands. Christmas, Caroline, Vostok, and Flint Islands were in the intermediate area between the wet and dry zones. There is, however, a considerable overlap in annual rainfall between the wet and dry zones. For example, on Fanning which is relatively wet, the annual rainfall has varied from 119 cm (47 in.) to 531 cm (209 in.), whereas on Malden, which is relatively dry, it has varied between 10 cm (4 in.) and 239 cm (94 in.).

Fig. 21

Fig. 22

The variability in annual and monthly rainfall for Palmyra, Washington, Fanning, Christmas, and Malden Islands is demonstrated in Figure 23. Table 3 shows that the average annual rainfall at Fanning was 213 cm (84 in.) whereas that at Malden reached only 71 cm (28 in.). But the variability in rainfall was only 41% at Fanning compared with 67% at Malden. Furthermore, the percentage frequency of dry months was usually higher at Malden than at Fanning. Seelye (1950) found that for the years examined, 52% of all months were dry at Malden compared with only 30% at Fanning. At Malden, the rainfall is usually meager; a few exceptionally wet months accounted for most of the total rainfall

Fig. 23
Table 3

The months of the highest and lowest average rainfall are
igs. 24,25 also given in the maps in Figures 24 and 25. According to Figure 24, the month of highest average rainfall is in March at Kingman Reef, Palmyra, Starbuck, Caroline, Vostok, and Flint, in April at Washington, Fanning, Jarvis, and Malden, and in May at Christmas. The month of least average rainfall is September at Kingman Reef, October at Palmyra, Washington, Starbuck, Caroline, Vostok, and Flint, and November at Fanning, Christmas, Jarvis, and Malden (Fig. 25).

The most detailed climatological data on any of the islands in the Line group come from Christmas Island. Jenkin and Foale (1968), who surveyed the coconut-growing potential of Christmas Island, did a detailed analysis of the climatological data collected there. Some of the results of their study are presented in the sections that follow.

CLIMATE AT CHRISTMAS ISLAND

Christmas Island, which lies within the equatorial dry zone that extends as a narrow belt across the central and eastern Pacific Ocean, is moderately dry (Jenkin and Foale 1968). Its climate may be summarized as follows:

Rainfall

Christmas Island is considered moderately dry with an average annual rainfall of about 87 cm (34 in.). However, the annual rainfall, given in Table 4, has varied widely from very dry (18 cm or 7 in.) to wet (262 cm or 103 in.). About 5 years out of every 20, the annual rainfall is likely to be below 51 cm (20 in.) and in about 8 out of every 20, it is likely to be above 99 cm (39 in.). March, April, and May were usually the wettest months and October and November the driest. The annual rainfall total at Christmas Island can be predicted from the rainfall in the first months of the wet season at locations where the wet season begins earlier than at Christmas Island. A highly significant positive correlation ($r = +0.66$) existed between the annual rainfall at Christmas Island and the sum of the rainfall for the months of December of the previous year and January of the same year at Fanning Island. The regression equation is

Table 4

$$x_1 = 510 + 31.6\ y_1$$

$$\text{or } x_2 = 20.09 + 1.25\ y_2$$

where x_1 = annual rainfall at Christmas Island, mm

x_2 = annual rainfall at Christmas Island, inches

y_1 = sum of rainfall for December of the previous year and January of the same year at Fanning Island, mm

y_2 = sum of rainfall for December of the previous year and January of the same year at Fanning Island, inches

Temperature

There was little variation in temperature from month to month (Table 5). Monthly maximum temperatures were usually highest in November and December whereas the monthly minima were lowest in June. Diurnal variation was also very small with maximum temperatures usually occurring at about 1400 h and minimum at about 0600 h.

Atmospheric Pressure

Atmospheric pressure varied only slightly not only from month to month but also diurnally. The pressure was usually lowest at 1500 h and highest at 0800 h. The average mean monthly atmospheric pressure at 0800, 1400, and 2000 h in 1953-65 is given in Table 6.

Relative Humidity

Table 7 gives the data on relative humidity at Christmas Island. September, October, and November had the lowest relative humidity, whereas March and April had the highest. Diurnally, the lowest humidity usually occurred between 1200 and 1400 h and the highest between 0000 and 0600 h.

Cloud

The cloud cover was generally consistent with the relatively low rainfall occurring on Christmas Island, reaching its highest
Table 8 percentage in March-April and lowest in September (Table 8). Consistentl greater cloud cover was experienced at 0800 and 1400 h than at 2000 h.

Sunshine

Because no sunshine data were available for Christmas Island, Jenkin and Foale (1968) calculated hours of sunshine from cloud cover
Table 9 (Table 9). They estimated that the average number of hours of sunshine for the whole year was 9.5 h/day. The greatest number of hours usually occurred in September and the least in April.

Wind

The average wind speed at Christmas Island showed little
Table 10 variation not only by time of year but also by time of day (Table 10). January usually had the highest wind speed and May the lowest. Diurnally winds were generally higher at 1400 h than at 0800 or 2000 h. Periods of calms were rare; they accounted for less than 2% of all observations. The wind direction was predominantly due east throughout the year and winds from the southwest and west were very rare. The northeast winds constituted only a small percentage of the total but they were important as the main rain-bearing winds. The infrequent westerly wind was usually accompanied by very heavy rain as a result of severe atmospheric disturbance. Christmas Island lies outside the Pacific hurricane belt.

OCEANOGRAPHIC CLIMATE

A review of the oceanographic observations for this region can be found in Barkley (1962, see footnote 3). His text, intended only as a review of salient features, is briefer than a complete discussion of the oceanography of the area warrants; however, Barkley provides an excellent bibliography where additional information and detailed treatment of certain features may be found.

The following sections discuss the horizontal and vertical distribution of temperature, salinity, oxygen, and phosphate, surface currents, upwelling, and the equatorial undercurrent in the Line Islands region.

TEMPERATURE

g. 26 Figure 26 shows the sea-surface temperature in 1954-61 at Christmas Island (Barkley 1962, see footnote 3). The daily observations at Christmas Island were smoothed by Fourier analysis of 15-day mean values. The figure illustrates that surface temperature went through seasonal and longer term changes at Christmas Island. Waters around Christmas Island were characterized by year-to-year changes in temperature which were as great as, or greater than, the regular seasonal changes (Barkley 1962, see footnote 3). In 1956 and 1958, when there was unusually warm water off the American coast, the Christmas Island temperatures reflected the change with a rapid increase in temperature early in 1957, followed by a gradual decrease to lower values in subsequent years.

Seasonal changes in sea-surface temperatures on a larger scale can be seen by examining the monthly sea-surface isotherms in the vicinity of the Line Islands. Figures 27a to 27ℓ, adapted from U.S. Navy Hydrographic Office (1944), World Atlas of Sea Surface Temperatures, show the surface water isotherms between lat. 30°N and 20°S and between long. 120°W and 170°E. The seasonal shifting of the isotherms latitudinally can be seen by examining the position of the 28°C (80°F) isotherm. In February, it was close to the northern Line Islands at about lat. 7°N between long. 155° and 160°W, but by September it was positioned farther north at about lat. 20°N in the vicinity of the Hawaiian Islands.

Fig. 27

Temperatures also reveal the changes that occur at the surface across the main features of the equatorial zonal circulation in the vicinity of the Line Islands. Figure 28 depicts the surface temperature along long. 150°W plotted against latitude across the equatorial current systems in the central Pacific Ocean (Austin 1954a). For reference, the major surface currents are shown in Figure 29. By examining temperature sections, Austin found that the North Equatorial Current extended south to about lat. 10°N, the Equatorial Countercurrent was between lat. 10° and 5°N, and the South Equatorial Current extended from lat. 5°N to the southern limit of the section. The striking features of the temperature section were the rise in surface temperature along the countercurrent and the decrease at lat. 1°S where the equatorial divergence is centered. The cooler surface water here reflected not only the mixing of deeper waters with those at the surface but also advection from the east in varying degrees (Austin 1960).

Fig. 28

Fig. 29

To further demonstrate the upward movement of cooler water at the equator, the vertical distribution of temperature in the Line Islands in the form of two north-south sections was reproduced in
ig. 30 Figure 30. Because temperature is the major determinant of density in the equatorial Pacific, the slope of the isotherm was a good indicator of the density distribution and, therefore, of the equatorial current structure (Barkley 1962, see footnote 3). For example, the downward slope of the isotherms north of lat. 10°N was associated with the westward-flowing North Equatorial Current. At the equator, the presence of cooler water at the surface resulted from vertical mixing. Two separate physical processes were involved in the mixing process (Austin 1960). One was related to divergence of the surface water under the influence of winds with an easterly component. The other was mixing by the winds. Divergence brought water of high density, lower oxygen content, and somewhat higher plant nutrient content to the surface at this latitude. The relationship between temperature and variation in nutrients
ig. 31 (phosphate) at the sea surface near the equator is shown in Figure 31. The tongue of cold water along the dark shading indicates masses of high nutrient waters.

The divergence of surface water and the accompanying upwelling which were associated with the equatorial current system produced considerable variation in the depth of the thermocline in the vicinity of the Line Islands. Figure 32 shows that north of the equator between long. 150° and 160°W, the thermocline varied between 30 and 213 m (100 and 700 ft) (Austin 1960). At or near the equator, Austin found it generally difficult to get an objective determination of the thermocline depth because in this region, the bathythermograph (BT) traces often showed either more than one inflection of the curve or a continuous negative gradient from the surface to the maximum depth of the BT trace. This region is indicated in shading in Figure 32. Temperature sections showing the variation in the depth of the thermocline in a north-south direction along long. 158°W can be seen in Figures 33 and 34. The depth of the thermocline varied widely. Figure 35 shows typical BT traces for various regions crossed in August-December 1951.

Fig. 32

Figs. 33,34

Fig. 35

Austin (1960) also demonstrated a rapid east-west deepening of the thermocline between long. 125° and 160°W. To illustrate, temperature-depth sections from BT's taken at eight positions along the equator are shown in Figure 36. The top of the thermocline was at 150 m (492 ft) near long. 155°W but was found at only 50 m (164 ft) near long. 125°W. The thermocline deepened slightly east of long. 120°W.

Fig. 36

SURFACE CURRENTS

The Line Islands are situated almost entirely within the Equatorial Countercurrent and the South Equatorial Current (June 1951). The North Equatorial Current, which remains in the northern hemisphere as it moves across the Pacific, often extends southward to about lat. 8°N in the vicinity of Kingman Reef. The South Equatorial Current flows on both sides of the equator and reaches northward to about lat. 5°N roughly in the vicinity of Washington Island. Lying between the two westerly flowing equatorial currents is the Equatorial Countercurrent flowing eastward at velocities up to 102 cm/sec (2 knots) at the surface. The countercurrent moves farther north of the equator during the northern summer, when it is strongest.

igure 37
ootnote 4

Charts of monthly surface currents around the northern Line Islands, shown in Figures 37a to 37ℓ,[4] were obtained from U.S. Navy Hydrographic Office (1950), Atlas of Surface Currents, Northwestern Pacific Ocean. The following description of the speed and direction of surface currents around the northern Line Islands is from Barkley (1962, see footnote 3)

In January-February, the countercurrent appears quite weak and there is a slight intensification of the South Equatorial Current. In March, the surface currents from north of lat. 8°N and south of lat. 5°N flow west and northwest at speeds of 18 to 28 km/day (10 to 15 mi/day) with some values as high as 37 km/day (20 mi/day). In between these latitudes, there is the eastward flowing countercurrent

with speeds of less than 18 km/day (10 mi/day). In April, there is almost no trace of the countercurrent at the surface; the surface flow is almost all westerly with some northward component. In the north, the general flow is estimated to be 18 km/day (10 mi/day) with speeds up to 37 km/day (20 mi/day) near the surface. Conditions in May resembled those in March. In June, the easterly flow occurs near lat. 5°N in the west and at lat. 6°-7°N in the east; current speeds of between 28 and 37 km/day (15 and 20 mi/day) are less common in the westerly equatorial currents, but higher velocities occur in the region of the countercurrent, which becomes well developed in July at the surface near lat. 5°-9°N. Velocities of over 28 km/day (15 mi/day) are common. The westward flow near Christmas Island is more intense with speeds of 37 km/day (20 mi/day). Currents in August-October are similar to those in July. The countercurrent diminishes in intensity as the year progresses, with other currents remaining steady.

The generally accepted concept of a zonally oriented flow pattern of the South Equatorial Current between the equator and the countercurrent has been modified by Murphy and Shomura (1972). They argued that the circulation between the equator and the countercurrent is exceedingly complex and as yet imperfectly known. The evidence examined suggested that the region between long. 120°W and 180° is not a single east-west system with respect to identity of its water. Rather, the water flow near the equator differs from the usual concept in that empirical measurements suggested both a northward and westward motion of the same magnitude. The model proposed by Murphy and Shomura,

therefore, considered the circulation in this region as a series of
g. 38 adjacent north-westerly flowing cells (Fig. 38).

UPWELLING

The circulation in a north-south plane in the central equatorial Pacific was discussed by Cromwell (1951, 1953). Examination of meridional sections revealed clearly the well-known equatorial upwelling but did not support the thesis that upwelling was occurring at the northern boundary of the countercurrent. Actually, Cromwell believed that horizontal convergence and sinking were apparently associated with an equatorial front, which separated dense upwelled water near the equator from water of lesser density which was usually found in the surface layer of the South Equatorial Current. The front did not coincide with the northern boundary of the countercurrent. Therefore, he proposed a model based on isentropic principles, which relates the transverse circulation near the equator to the winds. In terms of this model, Cromwell showed that there is a zone of horizontal divergence and an adjacent zone of convergence near the equator. The boundary between north-south convergence and divergence, he hypothesized,
g. 39 shifted latitudinally depending on wind direction (Fig. 39). The divergence feature of Cromwell's model explained the equatorial upwelling
ig. 40 whereas convergence produced significant sinking. Figure 40 shows the circulation in a north-south plane across the equator during southeast trade winds.

Briefly, the model proposed that under the stress of easterly winds, the surface water would move in a westerly direction at the equator, but the coriolis force north and south of the equator would tend to deflect the surface water poleward (Sette 1955). As the water moved away from the equator, deeper water would rise toward the surface. When there were northerly or southerly components in the easterlies, asymmetry was introduced and the center of upwelling was displaced. For example, southeast trades would displace the center of upwelling to the south of the equator.

North of the equator, convergence occurred as the denser upwelled water sank between the center of upwelling at the equator and the southern edge of the lower density water of the countercurrent which flows from west to east (Sette 1955). At deeper levels, sinking water may turn southward thus completing a cell, or it may move northward and dive under the countercurrent.

EQUATORIAL UNDERCURRENT

The first clue to the existence of a submerged current near the equator was provided through observations on the drift of longline fishing gear in the central equatorial Pacific. The longline gear, suspended from buoys and floating freely in the water, has the main mass of fishing lines in the lower part of the surface layer (Cromwell, Montgomery and Stroup 1954). Set near the equator a number of times during exploratory fishing cruises, the gear moved eastward in spite of

opposing trade winds, currents, and seas at the surface. This suggested that a submerged current was prevalent near the equator. Cromwell et al. (1954) proved the existence of this eastward moving current in the lower part of the surface layer and upper thermocline by using surface and deep drags. The undercurrent is depicted in Figure 41.

Fig. 41

PLANKTON

Plant and animal life in the ocean are dependent on the meridional circulation just described. The introduction of nutrients into the euphotic zone by upwelling and vertical mixing near the equator increases the phytoplankton and then the zooplankton population. King and Demond (1953) found that by tropical standards, there was a relatively large standing crop of zooplankton near the equator and in the Line Islands region from Christmas to Palmyra Islands (Fig. 42). In general, in the northern summer (June-November), zooplankton abundance reached a maximum at lat. 2°S and long. 150°W near Palmyra; standing crops of more than 50 cc/1,000 m^3 of water strained were common at this time. In the northern winter (December-May), the area of maximum abundance was about the same, but the standing crop was only between 25 and 50 cc/1,000 m^3. In all cases, standing crops of less than 25 cc/1,000 m^3 were found south of the equator and northwest of the Line Islands.

Fig. 42

Fig. 43 Figure 43 shows the north-south variation in zooplankton abundance (Cromwell 1953). The data were collected during 11 crossings of the equator between long. 140°W and the 180th meridian, a region where southeast trade winds predominated. Maximum zooplankton concentration was apparently related to the equatorial upwelling, because the peak in abundance occurred at the equator. The bulk of the plankton, however, was displaced slightly north which was consistent with the meridional circulation described by Cromwell (1953).

The middle and right panels of Figure 43 show zooplankton abundance based on net hauls made concurrently with hydrographic stations in January-February 1950 and in July-August 1950, respectively. Cromwell (1953) stated that these distributions showed the influence of a meridional circulation near the equator during a southeast wind when a front was present. The middle panel showed a rather abrupt decrease in zooplankton abundance northward across the front whereas the third panel indicated that the zooplankton was concentrated near the front.

In a subsequent study, Hida and King (1955) discovered other interesting facts about the distribution of zooplankton in the central equatorial Pacific. For example, surface hauls at night yielded significantly greater volumes than day samples, but intermediate- and deep-level hauls showed no significant differences in volume between day and night samples (Table 11). They also concluded that the area between lat. 2°S and 8°N at long. 150°W contained the greatest amount of zooplankton, with a peak in abundance at lat. 1°S.

The results of still other cruises during which plankton samples were collected showed the relationship of zooplankton to the various components of the equatorial current system. Having confirmed earlier findings that zooplankton concentration was greatest in the region of upwelling and divergence (King and Demond 1953), King and Hida (1957) discovered also that the average zooplankton volume for the convergent zone and the countercurrent was greater than for the South Equatorial Current south of the equator (Fig. 44). They reasoned that this asymmetrical distribution may result from the prevalence of southeast trades in the central equatorial Pacific. Furthermore, oceanographic fronts in the transition zone between the equator and the southern boundary of the countercurrent separated areas of high and low zooplankton abundance (Fig. 45).

ig. 44

ig. 45

Zooplankton abundance differed not only in a north-south direction, but also in an east-west direction. King and Hida (1957) showed that within the equatorial region, there was a gradient of increasing zooplankton abundance from long. 180° to 150°W. The west to east gradient correlated positively with average wind velocity but negatively with thermocline depth.

King and Hida (1957) also found a highly significant positive correlation between zooplankton volume and surface inorganic phosphate. The highest concentration of phosphate occurred in the divergent zone at the equator, as did the greatest zooplankton abundance. But when examined by longitude and season, high phosphate concentrations appeared to be inversely related to zooplankton and yellowfin tuna

catches. King and Hida concluded that this type of relationship may be the result of differences in rate of utilization of phosphate

Figs. 46,47 (Figs. 46 and 47).

TUNA RESOURCE

In the early 1950's it was hypothesized that the equatorial divergence-convergence system 2,200 km (1,200 mi) south of Hawaii would be effective as a large-scale mechanism for producing important concentrations of fish (Sette 1955). Sixteen hydrographic traverses to study the equatorial current system provided data that proved there was indeed an upward movement of water at the equator (Cromwell 1951), accompanied by a greater concentration of zooplankton (King and Demond 1953). The logical next step was to assess the potential tuna resource

Fig. 48 in this area of enrichment (Fig. 48).

Preliminary reconnaissance of the central equatorial Pacific determined that several kinds of tuna, notably yellowfin and skipjack, constituted a highly promising fishery resource. The sections that follow present some of the results obtained by research and commercial vessels that were engaged in assaying the fish stocks in the central equatorial Pacific through systematic fishing surveys.

BIRD FLOCK AND FISH SCHOOL SIGHTINGS

Pole-and-line and purse seine gear can be used only on surface schools of tuna. Because the majority of surface tuna schools in the central Pacific are located in association with bird flocks, the rate of sightings of bird flocks gives an indication of the relative abundance of tuna schools.

During the cruise of the Oregon, Smith and Schaefer (1949) observed that between Palmyra and Jarvis, and between Jarvis and Christmas Islands, there were numerous skipjack tuna schools often associated with large flocks of birds. Skipjack and yellowfin tunas were frequently taken on trolling lines during these runs, but the schools were reported to be very wild and erratic in behavior and could not be chummed to the vessel.

Murphy and Ikehara (1955) summarized sightings of bird flocks and fish schools and found that in the Hawaiian Islands, skipjack tuna was by far the most commonly sighted tuna. In the Line and Phoenix Islands, however, skipjack tuna formed a substantial part of the surface sightings but they were considerably outnumbered by yellowfin tuna. On the other hand, seasonal abundance was remarkably similar among the three island groups studied by Murphy and Ikehara (Table 12). The peak in abundance of skipjack tuna, yellowfin tuna, and all species combined occurred in June-November (Fig. 49). They suggested that because of this similarity in seasonal abundance, factors common to all these island groups were operating. But common factors that might

ble 12

g. 49

affect fish abundance in all three island groups simultaneously could not be isolated because these groups were widely separated in space and were affected by different current systems. Murphy and Ikehara suggested that possibly these seasonal cycles merely reflected changes in apparent abundance brought about by fluctuations in bird populations because most tuna schools were located by birds.

Murphy and Ikehara (1955) also found variation in species composition of tuna school sightings with distance from land. In the Line and Phoenix Islands, yellowfin tuna were usually near land whereas skipjack tuna predominated in the semioceanic zone which was

Table 13 between 111 and 334 km (60 and 180 mi) from land (Table 13). In the Hawaiian Islands, all yellowfin tuna schools sighted were close to the islands although skipjack tuna predominated there as well as offshore. Furthermore, they concluded that the rate of sighting in the area immediately surrounding the islands (within 111 km or 60 mi from land) was about the same (1.3 versus 1.8/day) as in the semioceanic areas.

Summaries of bird flock and fish school sightings have also

Footnote 5 been prepared by Waldron (1964) and Naughton.[5] To illustrate the variation in school sightings not only seasonally but also among years in the Line Islands region, data within the 5° square with the highest

Table 14 amount of scouting effort were summarized (Table 14). The results showed that bird flock sightings were usually lowest in March-May and highest in June-August. And although Waldron (1964) showed no sightings of skipjack tuna schools and a very low rate of sightings for

total schools in June-August, Naughton showed that the rates of sightings of both skipjack tuna and total schools were highest in June-August. Charts summarizing sightings of bird flocks, skipjack tuna schools, and total fish schools by time-area units bounded by lat. 30°S and 30°N, and long. 110°W and 120°E are shown in Figures

ig. 50 50a through 50ℓ.

TUNA FISHING TRIALS

In undertaking the development of mid-Pacific tuna resources after World War II, several private and semi-private attempts were made to fish for tuna in the Line Islands (Sette and staff 1954). These exploratory fishing ventures were started with the idea of obtaining quick results by sending skilled fishermen on California-type bait boats to places presumed to be rich tuna grounds. Tuna were caught on each of these ventures, but not in commercial quantities.

In the early 1950's, the Pacific Oceanic Fishery Investigations (POFI) launched an intensive investigation into the fishing potential of the Line Islands. In the following sections, tuna fishing trials in the Line Islands by private, semi-private, and government vessels using various fishing methods are discussed.

Pole-and-Line Fishing

The success of pole-and-line fishing depends entirely on a constant and ample supply of live bait. Many different species of small fish offer possibilities as live bait; however, not all have the qualities that make a small fish a good baitfish. These qualities, brought out and discussed at the Tuna Baitfish Workshop held on 4-6 June 1974 in Honolulu, Hawaii, include availability, behavior when chummed at sea, survival in captivity, fishermen acceptance, color and color pattern, body form, and size.

On exploratory fishing cruises to the Line Islands, species most commonly seen or captured for bait included mullet, goatfish, and milkfish (Fig. 51). At Palmyra Lagoon, Smith and Schaefer (1949) reported that the only fish seen that might be used for bait was small mullet, which occurred in quantities along the beaches. They reported seeing no fish of either the silverside or herring families, day or night. At Christmas Island they found bait in the lagoon and reported seeing large quantities of mullet and goatfish, but no fish of the silverside, anchovy, or herring families. They found some silverside just offshore of the island during night baiting operations. The bait catch at Christmas Island consisted of 30 scoops (about 5 kg or 10 lb of baitfish per scoop) of 15-cm (6-in.) mullet and a few goatfish of similar size.

Fig. 51

June (1951) provided additional information on bait resources at Palmyra Island. He indicated that mullet suitable for live-bait fishing was most abundant in East Lagoon. The mullet varied in size from 3 to 15 cm (1 to 6 in.) and occurred in schools varying in size from a few scoops to a hundred or more scoops. Small milkfish (5-8 cm or 2-3 in.) were also found along the beaches. Goatfish (3-10 cm or 1-4 in.) occurred in some quantity in Palmyra's West Lagoon. June interviewed Civil Aeronautics Administration personnel stationed on the island and learned that small mullet were most abundant in summer.

Ikehara (1953) also discussed various attempts to capture bait in the Line Islands by the Pioneer and Calistar, tuna clippers which conducted exploratory fishing in the vicinity of the Line Islands in 1947 and 1949, respectively. In late 1947, the Pioneer caught about 400 scoops of mullet at Palmyra and 200 scoops at Christmas Island. The Calistar, on the other hand, reported very poor baiting, with a catch of only eight scoops of bait-size mullet at Palmyra.

In January-February 1953, the Tradewind, a 24-m (80-ft) Hawaiian sampan was chartered in an attempt at pole-and-line fishing in the Line Islands (Yuen and King 1953). The bait catches, mostly mullet, from this exploratory fishing operation were 242 buckets at Palmyra (about 2 kg or 4 lb of baitfish/bucket), 85 buckets at Fanning (about 5 kg or 10 lb/bucket), and 19 buckets at Christmas Island (7 kg or 16 lb/bucket) (Ikehara 1953; Yuen and King 1953). Data on baiting by research vessels in 1950-51 are given in Table 15.

Summaries of baiting operations and bait surveys conducted in 1955-64 are given in Tables 16 and 17, respectively (Uchida, undated internal report).[6]

Tables 16, 17
Footnote 6

In general, only a limited number of observations on bait have been made in the Line Islands. Baiting operations by both commercial and research vessels have been moderately successful, but based on the results of baiting surveys and operations, it is apparent that bait is not in constant supply in any of the islands in the Line Island group. For example, Ikehara (1953) indicated that in June 1951, only a few aholehole were seen in Fanning Lagoon, but in February 1953 the Tradewind caught a good supply of bait-size mullet there. Ikehara also noted that the catchable bait at Palmyra is usually exhausted after only a few days of baiting.

June and Reintjes (1953) provided an evaluation of tuna-bait resources of Palmyra, Fanning, and Christmas Islands. They concluded that Palmyra's lagoons offer stocks of mullet and other small fish that are suitable as supplemental bait to more desirable baitfish species. Bait surveys at Fanning Island were not sufficiently comprehensive to permit sound conclusions about the relative abundance of baitfish stocks. Small fish suitable as supplemental live bait were available in the lagoon at Fanning, but only small quantities were seen. At Christmas Island, June and Reintjes observed large quantities of bonefish and scattered schools of mullet in the lagoon. Because of the size of its lagoon, Christmas Island is potentially the most important baitfish source in the entire Line Island chain. The reported

occurrence of the Hawaiian silverside (or a closely related species) in the lagoon at Christmas Island requires further investigation.

Concerning pole-and-line fishing in the Line Islands, Smith and Schaefer (1949) reported poor results. On runs between Palmyra and Jarvis and between Jarvis and Christmas Islands, the Oregon caught skipjack tuna and yellowfin tuna on trolling lines, but the schools she encountered were wild and erratic and usually could not be chummed to the stern of the vessel. At Jarvis, the Oregon succeeded in fishing a school of "two-pole" yellowfin tuna and caught 15 fish; around Christmas Island, however, only one large school of fish was seen.

In late 1957, the Pioneer caught 6.4 metric tons (MT) [7 short tons (ST)] of yellowfin tuna mostly around Fanning and Christmas Islands (Ikehara 1953). But in February 1949, the Calistar, carrying 1,800 scoops of anchoveta caught at Magdalena Bay before departing for the Line Islands, caught about 45 MT (50 ST) of yellowfin tuna at Fanning Island and 13.5 MT (15 ST) of yellowfin tuna at Palmyra Island. The exploratory fishing cruise of the Hawaiian sampan, Tradewind, produced 6.5 MT (7 ST) of yellowfin tuna at Palmyra Island and 5.9 MT (6.5 ST) at Fanning Island.

Data from Ikehara (1953) showed that less time was expended in scouting and fishing in the Line Islands than in other areas of the central Pacific and that the catch was larger (Table 18). Furthermore, a greater percentage of the fish schools sighted there exhibited behavior that permitted the vessel to get into a chumming position. And consistently greater catches of tuna were made from each school fished. The main obstacle to successful pole-and-line fishing in the Line Islands then, is a constant and ample supply of live bait.

Purse Seining

The scarcity of live bait in the Line Islands made it desirable to develop an alternate method of capture; therefore, purse seine fishing was attempted there in 1950-51. After five exploratory cruises to this area, Murphy and Niska (1953) reported on the purse seining potential of the Line Islands. The cruise periods were 22 April-7 June 1950; 2-19 September 1950; 1 November-1 December 1950; 11-23 February 1951; and 5 April-12 May 1951. A brief summary of each of these cruises is given below.

22 April-7 June 1950--The John R. Manning, research vessel of POFI, predecessor of the National Marine Fisheries Service, scouted 310 h and sighted 12 yellowfin tuna, 8 skipjack tuna, 5 unidentified, and 3 mixed schools during the cruise. Two sets with the purse seine around the tuna schools were unsuccessful.

2-19 September 1950--The Manning scouted Jarvis, Christmas, Palmyra, and Kingman Reef a total of 85 h during this period and sighted eight yellowfin tuna and six unidentified tuna schools. Four sets were made on schools off Christmas Island, but all were unsuccessful.

1 November-1 December 1950--The Manning scouted near Kingman Reef, Christmas, Fanning, Washington, and Palmyra Islands for a total of 226 h and sighted nine yellowfin tuna, seven skipjack tuna, and six unidentified schools. Murphy and Niska reported that the schools were usually close to the islands or too elusive to set on; therefore, only one set was made at Fanning Island and that one failed to produce fish.

11-23 February 1951--On this cruise, the Manning scouted waters off Jarvis, Christmas, Fanning, Washington, Palmyra, and Kingman Reef for 104 h and sighted only one yellowfin tuna, two skipjack tuna, and two skipjack-yellowfin tuna schools. No sets were made on any of the tuna schools sighted during the cruise. Strong winds limited operations to the lee of the islands.

5 April-12 May 1951--The Manning scouted waters near Kingman Reef, Palmyra, Fanning, Christmas, and Washington Islands during the cruise for 208 h and sighted only two yellowfin tuna, two skipjack tuna, and two unidentified tuna schools. Five sets during this cruise were all unsuccessful.

In summary, five trips over a 12-month period to the Line Island were made. The vessel devoted 933 h scouting and sighted 75 schools of tuna, but because of proximity of reefs and wild behavior of the schools, only eight sets were possible. On six of these sets, fish were in the circle as pursing began, but sounded out before pursing was completed. The deep thermocline in this area enabled the tuna schools to sound beneath the net.

Trolling

Trolling offered still another alternative to the ways tuna could be captured in the Line Islands. Not requiring live bait, trolling was used as a secondary and incidental procedure during the normal course of scouting for bird flocks and fish schools on purse seining operations.

In the late spring of 1950, the John R. Manning, a research vessel operating out of Honolulu, surveyed the Line Islands with purse seine and trolling gear. Bates (1950), who reported on this trolling survey, selected Kingman Reef and Palmyra, Washington, Fanning, and Christmas Islands for exploration because of their proximity to the upwelling along the equator.

In general, the Manning trolled within 11 km (6 mi) of the islands or reef. Bates (1950) found yellowfin tuna concentrated in the lee of the islands during periods of northeast and east winds. The majority of the strikes on the trolling lines occurred within 4 km (2 mi) of the beach, on and around the reefs and in shoal areas.

Manning circled Kingman Reef along the course line shown in Figure 2 in 3 h (Bates 1950). Off the northwestern coast of Kingman Reef, shown by the shaded area in the figure, Manning caught fish
ble 19 regularly; the results are given in Table 19. Eighty hours of trolling around the reef produced 373 tuna or 0.79 tuna per line-hour. Bates (1950) also made observations on some large schools of tuna sighted near
ble 20 the reef (Table 20).

Sharks were a considerable nuisance at Kingman Reef (Bates 1950). Gray shark, Eulamia sp., 1.5-1.8 m (5-6 ft) in length, followed the Manning and frequently struck the lures, even at night. Manning landed 14 sharks. A number of tuna and wahoo were damaged by sharks when delays occurred in hauling the trolling lines.

Manning circled Palmyra three times, each circle requiring 2.5 h. Bates (1950) reported that large flocks of birds were usually observed working near the reefs on the eastern and western sections of the island. Large numbers of porpoise were also spotted on the eastern side. Surface trolling was best in the shaded area shown in Figure 3; therefore, most of the trolling was confined to this area. Birds were numerous, frequently flocking together to work over concentrations of food organisms. Tunas were often seen jumping under these fast-moving flocks.

From Table 20, it appears that Manning's catch was relatively poor. Bates pointed out, however, that previous reports by people familiar with Palmyra's trolling potential indicate that poor

fishing is not a year-round situation. Actually, the largest single day catch of yellowfin during the entire cruise was made at Palmyra. There, 52.75 h of trolling produced 193 tuna weighing 2.1 MT (4,613 lb). The catch per line-hour reached 0.58 fish.

Figure 4 shows the track of the Manning at Washington Island which required 3 h to circle. Trolling, confined primarily to the shaded area in the figure, produced catches in numbers and tonnage secon only to Kingman Reef (Table 19). In 58.25 h, Manning caught 196 tuna weighing 3.2 MT (7,101 lb). The catch rate here was 0.53 tuna per line-hour.

Manning encountered very few tuna at Fanning Island (Bates 1950). No birds or fish were seen in the 4 h required to circle the island. Therefore, most of the trolling was confined to the shaded area shown in Figure 5. Small schools of yellowfin tuna were encountered off Whaler's Anchorage and only a few fish were caught. On the whole, bird activity was far less than at any of the other areas surveyed. Table 19 shows that 32.5 h were devoted to trolling around Fanning but only 15 tuna were taken. The catch of 0.08 tuna per line-hour was extremely low

Table 19 also shows that in 62 h of trolling around Christma Island, 105 tuna weighing 2.1 MT (4,690 lb) were caught at a catch rate of 0.28 tuna per line-hour. Bates discovered that on those days when yellowfin tuna bit well (12 and 13 May), they were feeding at the surfac on small, red crab megalop larvae. The disappearance of these crabs was reflected in an abrupt decline in troll catches the following day.

For all the Line Islands, Manning trolled 285.5 h and caught 882 yellowfin tuna weighing 13.3 MT (29,319 lb). Also taken were 178 wahoo or ono weighing 217 MT (5,888 lb) and smaller numbers of skipjack tuna, rainbow runners, *Elagatis bipinnulatus*, and barracuda, *Sphyraena* sp.

Bates compared the troll catches of yellowfin tuna from Kingman Reef, Palmyra Island, and Washington Island by 2-h periods to determine whether availability of tuna varied by time of day among the
able 21 areas (Table 21). He concluded that tuna in these islands were caught with near-equal success throughout the day.

Bates also acquired information from a Captain Northrup Castle of Honolulu, who had fished commercially throughout the Line Islands. According to Captain Castle's account, the main body of birds on Christmas Island travel each morning in a northerly direction to an area some 370 km (200 mi) out to sea on a course line to Honolulu. According to Bates, this is the area of convergence of the Equatorial Countercurrent with a northwesterly current originating at Christmas Island (possibly the South Equatorial Current). Captain Castle stated that he saw boobies by the thousands working over a tremendous concentration of breezing yellowfin tuna. Some of the yellowfin tuna caught by Captain Castle exceeded 136 kg (300 lb).

Murphy and Ikehara (1955) also reported on the troll catches of several research vessels operating in the Line Islands. Their results showed that primary trolling in the Line Islands produced a much higher catch rate than in the Hawaiian Islands. The catch rate for tuna was
able 22 27.6 fish per 100 line-hours, practically all yellowfin tuna (Table 22).

The results of nine fishing cruises to the Line Islands by POFI research vessels from March 1955 to February 1956 were discussed by Iversen and Yoshida (1957). On these cruises, where both trolling and longlining were attempted, the troll catch amounted to 2,397 fish, 980 (41%) of which were yellowfin tuna. The remainder was made up of skipjack tuna (2%), wahoo (48%), and miscellaneous fish including rainbow runner, jack, dolphin, barracuda, red snapper, little tunny, needlefish, leatherjacket, and sharks (9%).

Detailed examination of trolling results led Iversen and Yoshida (1957) to conclude that yellowfin tuna catch rates in the Line Islands peaked in March-April (1.3 to 7.3 fish per hour) for all
Fig. 52 islands and were generally low the rest of the year (Fig. 52). They found that slightly higher catch rates occurred in the morning on
Fig. 53 some of the cruises (Fig. 53) and that yellowfin tuna were generally more abundant at Palmyra and Kingman Reef than at Christmas Island
Fig. 54 (Fig. 54). Bates (1950) also reported similar results.

Iversen and Yoshida (1957) compared their results with those obtained by Bates (1950) and Murphy and Ikehara (1955) and the data
Table 23 are given in Table 23. Of significance was the high catch rate of 3.1 fish per hour obtained in April-June 1950 and the low catch rates of 1.4 and 1.2 fish per hour calculated for the other two periods. They concluded that the abundance of yellowfin tuna in the Line Islands during the survey period was too low to encourage commercial exploitation by trolling vessels. Furthermore, there appeared to be a seasonal change in abundance, with catch rates in March-April usually higher than at other times of the year.

Species commonly taken in the Line Islands are given in Table 24. Murphy and Shomura (1972) listed 18 species of fish caught by longline but also included those likely to be captured by trolling or be seen at the surface in the central equatorial Pacific. Helfrich (1973) modified this list by adding rainbow runner and crevalles.

Longline Fishing

Despite consistent evidence of chemical enrichment of the surface layer at the equator through upwelling accompanied by a greater concentration of zooplankton in the vicinity of the equator than in adjacent latitudes, extensive surface fishing trials proved disappointing. Exploratory pole-and-line fishing with live bait, purse seining, and trolling produced little or no tuna in the zonal band of enrichment. There was, however, some good fishing in the immediate vicinity of some of the atolls in the Line Islands. The only method of fishing that proved satisfactory for sampling the large, pelagic, subsurface tunas was the longline, which can be fished at depths ranging from 30 to 133 m (100 to 400 ft).

The early longline fishing cruises to the central equatorial Pacific proved that there was indeed a concentration of deep-swimming yellowfin tuna which appeared to be associated with increased food supply from upwelled nutrient-rich water (Murphy and Shomura 1952, 1953a). The number of fish caught on these and subsequent cruises is given in Table 25. Figure 55 illustrates the catch rates of yellowfin

and other tunas between lat. 5°S and 15°N and between long. 150° and 170°W.

After the initial longline fishing survey, Murphy and Shomura suggested that the equatorial stocks of deep-swimming tunas appeared capable of supporting an American fishery. Based on a catch rate of 12.3 yellowfin tuna per 100 hooks in the survey area as opposed to 3 tuna per 100 hooks in the western Pacific, they concluded that there was a greater concentration of tuna in the central than in the western equatorial Pacific.

Catches made on subsequent longline cruises in 1952 gave evidence that the "rich zone" of yellowfin tuna in the equatorial region varied latitudinally and that this zone generally coincided with differences in the prevailing wind (Murphy and Shomura 1953b, 1972). During periods of northeast trades, yellowfin tuna was most abundant south of the equator; during southeast trades, north of the equator (Fig. 44). Peak abundance straddled the equator during variable winds.

High catches of albacore in southern latitudes on long. 169°W and 180° pointed to the possibility of commercial exploitation for this species (Murphy and Shomura 1953b). The results of experimental fishing also showed that gear with longer float lines, fishing at a deeper level, was more efficient in catching albacore.

The longitudinal variation in catch rates of yellowfin tuna and albacore was also investigated by Murphy and Shomura (1955). The results of four longline cruises in 1952 to the central equatorial Pacific between long. 120° and 170°W showed that at long. 120°W, where upwelling was very intense, yellowfin tuna catches were usually low. This condition suggested that the water had not been in the photosynthetic zone long enough to have developed a favorable food supply. Murphy and Shomura (1972) showed that the presence of colder water was associated with more phosphate, more zooplankton, and fewer yellowfin
ig. 56 tuna (Fig. 56). There were less phosphate, less zooplankton, and more yellowfin tuna associated with warmer waters. These differences reflected the time lapse after enrichment through upwelling. Variations at a geographical locality were believed to be in response to variations in wind flow that affected the rate of upwelling.

Six longline cruises in 1953 provided data that were consistent with earlier findings. Yellowfin tuna abundance continued to be centered in the region near the equator enriched by upwelling (Shomura and Murphy 1955). Furthermore, it became obvious also that the centers of abundance of bigeye tuna and albacore were away from
ig. 57 that of yellowfin tuna (Fig. 57). Bigeye tuna were most abundant in the region of the countercurrent and albacore most abundant south of the equator (Murphy and Shomura 1972). In terms of vertical distribution, Shomura and Murphy (1955) discovered that yellowfin tuna were taken more frequently on the deeper fishing hooks. Catches of bigeye tuna and albacore also showed this tendency, and to an even greater degree.

In 1952, after 2 years of study of the tuna resources around the Line Islands, POFI chartered a west coast purse seiner, Cavalieri, to fish on a semi-commercial basis with longline gear (McKernan 1953; Sette and staff 1954). Thirty-three days of fishing produced 41.4 MT (91,255 lb) of yellowfin and bigeye tunas. The Cavalieri's catch rate of 5.2 tuna per 100 hooks was twice as good as the average for Japanese vessels fishing in grounds west of 180°, although somewhat below the average catch rate of 6.3 tuna per 100 hooks for POFI research vessels. The venture proved that west coast fishing vessels of the Cavalieri type could be readily adapted to fish longline gear.

Not all the fish unloaded by the Cavalieri could be canned. McKernan (1953) reported that of the 41.4 MT (91,255 lb) of yellowfin and bigeye tunas delivered to the cannery, 12.6 MT (27,750 lb) were rejected because of "off-color." Rejected were 3.8 MT (8,500 lb) of
Fig. 58 bigeye tuna and 8.6 MT (19,000 lb) of yellowfin tuna. Figure 58 shows, by size, the percentage acceptance of yellowfin and bigeye tunas by the cannery.

The first full-scale commercial attempt by American fishermen to fish with longline in the central equatorial Pacific began in 1954. The North American and Alrita, working under a contract whereby they were paid by the government only to offset costs for gear and deck arrangements not normally used by these vessels, each made two trips fishing with longline (Iversen and Murphy 1955; Iversen and Yoshida 1956). In 121 fishing days, they landed four full cargoes of fish. On

the first set of cruises, each of the vessels averaged 1.59 MT (1.75 ST) of yellowfin tuna per day fished and on the second set about 1.61 MT (1.78 ST). These vessels found better fishing within 110 km (60 mi) of Christmas Island than at greater distances. Based on these results, Iversen and Murphy (1955) concluded that it was commercially practical for American fishing vessels with relatively small crews to fish for yellowfin tuna with longline in the central equatorial Pacific.

Encouraged by the North American's and Alrita's results, four other vessels: Brothers, Oceanic, Sea Hawk, and Commonwealth, attempted commercial fishing in the Line Islands area in 1954. Iversen and Yoshida (1956) analyzed the longline catch data collected not only by the American commercial fishing vessels but also by research vessels operating in the central equatorial Pacific. For the Line Islands area, they found a seasonal trend in yellowfin tuna catch rates, which were high in February and very low in July-August and again in October. In November, the catch rates increased slightly over those for the summer months but remained considerably lower than those of the early part of the year. Iversen and Yoshida found that the catch rates of Japanese longline vessels based at Pago Pago, American Samoa, showed a similar pattern. The results also showed that yellowfin tuna catch rates did not vary significantly among different localities close to the Line Islands. This indicated a random distribution of fish with respect to each individual island.

In an attempt to increase the efficiency of fishing with longline gear, a mainline of wire rope rather than the standard cotton was used on the cruises of the Brothers, Oceanic, and Commonwealth (Iversen and Yoshida 1956). Steel mainline had an advantage in that it could be spooled onto one large reel or drum whereas cotton mainline, joined in sections called baskets needed to be run through a longline hauler to be coiled before being placed in individual baskets (see Murphy and Shomura (1953a) for detailed description of the gear). Comparison showed that steel gear had a lower catch rate than fabric gear. The vessels experimenting with steel gear had difficulty with the steel mainline and lost many tuna, owing primarily to the lack of drag in the water and stretch in the mainline (U.S. Fish and Wildlife Service 1955). A test of both cotton and steel gear on a research vessel showed that although both gear caught about the same number of yellowfin tuna, the catch by steel gear consisted of fewer medium and large yellowfin tuna. Lack of resiliency in steel gear permitted a higher proportion of large tunas to struggle free of the hooks.

Other results reported by Iversen and Yoshida (1956) diverged sharply from previous observations. Shomura and Murphy (1955) found that the highest catches in the Line Islands area occurred in July-September in 1951-53, whereas Iversen and Yoshida reported that in 1954 the highest catches occurred in February. This discrepancy in the seasonal trend of catch, according to Iversen and Yoshida, is good evidence of a change in the abundance or distribution of yellowfin tuna, possibly related to a change in the environment.

Yellowfin tuna catches in the Line Islands are positively correlated with sea temperatures. But Tester (1956) pointed out that temperature change was not the direct cause of changes in tuna abundance. Rather, surface temperature was an indicator of the age of the water subsequent to upwelling, the coolest water being considered newly upwelled and warmer water as having been longer at the surface for tuna forage to develop in it.

Yellowfin tuna catch rates and sea-surface temperature
Fig. 59 obtained at Christmas Island in 1954 showed similar trends (Fig. 59). Both were relatively high early in the year and relatively low in late summer and fall.

Fig. 60 Figure 60 shows the longline catch rates calculated for March 1955 to February 1956 (Iversen and Yoshida 1957). In general, catch rates at insular stations (less than 18 km or 10 mi from land) were higher than those of oceanic stations, which were consistently low during the survey period. Insular catch rates showed considerable variation throughout the year and two possible causes were fishing at different seasons and fishing in different areas.

SIZE OF FISH

In the Line Islands region, surface yellowfin tuna caught by
Fig. 61 pole-and-line and live bait were usually small as seen in Figure 61. Murphy and Shomura (1972) reported that the average size of yellowfin tuna caught by this gear was about 13 kg (29 lb). Similarly, Ikehara

(1953) reported that most of the yellowfin tuna caught by pole-and-line weighed between 9 and 14 kg (20 and 30 lb). Ikehara also discovered that these small, "one-pole" fish often took the hook first when chumming began, but were soon displaced by large deep-swimming yellowfin tuna which required as many as six poles for one hook. He noted that this type of mixed-size schools occurred commonly in the Line Islands usually close to land. Non-uniformity in size of the yellowfin tuna made fishing difficult and hazardous; it often slowed fishing so that poor catches were made from good-biting schools.

Fig. 62 Concerning troll-caught fish, Figures 61 and 62 show the sizes of yellowfin tuna caught in the Line Islands. Murphy and Shomura (1972) gave the average size of troll-caught yellowfin tuna as 15 kg (33 lb). Bates (1950) showed that yellowfin tuna taken in a trolling survey in 1950 varied from 4 to 75 kg (8 to 165 lb) and averaged slightly over 15 kg (34 lb). Furthermore he noted that some lost fish were as large as 91 kg (200 lb). Overall, the size distribution of troll-caught yellowfin tuna from the Line Islands showed a pronounced mode between 7 and 8 kg (15 and 18 lb) and another between 26 and 29 kg (57 and 65 lb).[7] The size distribution of yellowfin tuna caught by trolling in a 1955-56 survey and reported by Iversen and Yoshida (1957), showed only a single mode that fell between 6 and 10 kg (14 and 21 lb) with a range of 2 to 67 kg (5 to 148 lb) (Fig. 63).

Footnote 7

Fig. 63

Like troll-caught fish, longline-caught, deep-swimming yellowfin tuna also had a wide variation in size (Fig. 61). But the size ranged from 5 to 92 kg (12 to 204 lb) (Shomura and Murphy 1955). Longline-caught yellowfin tuna averaged 55 kg (122 lb), or roughly four times the average weight of yellowfin tuna taken by pole-and-line fishing and trolling.

Yellowfin tuna sizes differed not only between the surface and deeper layers but also with distance from land (Shomura and
g. 64 Murphy 1955). Figure 64, which shows the size distribution of yellowfin tuna caught in oceanic and insular areas, illustrates that larger numbers of small yellowfin tuna were captured close to land. This fact has been substantiated by longline catches made in 1955-56. Iversen and Yoshida (1957) found that in the size distribution of oceanic yellowfin tuna, the single mode fell between 54 and 65 kg (119 and 144 lb) as seen in Figure 63. The size distribution of insular yellowfin tuna had a similar mode between 54 and 65 kg (119 and 144 lb), but it also included more small fish in relation to the large ones.

Another interesting fact about the tuna taken near the equator was the difference in size in an east-west direction across the Pacific. Examining tuna catches by longitude of capture, Murphy and Shomura (1953b, 1955) discovered that the sizes of longline-caught yellowfin and bigeye tunas in the oceanic areas increased from west to
gs. 65,66 east (Figs. 65 and 66). The explanation offered was that the growth rates of these tunas change across the Pacific, reflecting the relative

availability of food. Murphy and Shomura found this proposal compatible with estimates of upwelling. Whereas along the equator in the western Pacific between long 140° and 170°E there is no evidence of upwelling (Murphy and Otsu 1954), there is moderate to strong upwelling in the central Pacific between long. 180° and 150°W (Cromwell 1953; Murphy and Shomura 1953a, 1953b, 1955; Austin 1954a). And in the eastern Pacific between long. 145° and 120°W, upwelling appears to be very intense at various times of the year.

Size distribution of longline-caught albacore and bigeye tuna may be found in Figure 61 and of skipjack tuna in Figure 67. Whereas albacore caught in the central Pacific averaged 17 kg (37 lb) or only slightly larger than troll-caught yellowfin tuna, longline-caught bigeye tuna were by far the largest among the tunas taken near the equator. Murphy and Shomura (1972) gave the average size of bigeye tuna as 77 kg (170 lb). Skipjack tuna, taken only incidentally by longline gear, averaged 9 kg (20 lb).

Fig. 67

LITERATURE CITED

AUSTIN, T. S.

1954a. Mid-Pacific oceanography III, transequatorial waters, August-October 1951. In U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 131, 17 p., + figs. and station data.

1954b. Mid-Pacific oceanography Part V, transequatorial waters, May-June 1952, August 1952. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 136, 86 p.

1960. Oceanography of the east-central equatorial Pacific as observed during Expedition EASTROPIC. U.S. Fish Wildl. Serv., Fish. Bull. 168:257-282.

BATES, D. H., JR.

1950. Tuna trolling in the Line Islands in the late spring of 1950. U.S. Fish Wildl. Serv., Fish. Leafl. 351, 32 p.

BRYAN, E. H., JR.

1941. American Polynesia; coral islands of the central Pacific. Tongg Publishing Co., Honolulu, Hawaii, 208 p.

1951. Central and western Polynesia. In O. W. Freeman (editor), Geography of the Pacific, p. 394-422. John Wiley and Sons, Inc., N.Y.

CHAVE, K. E.

1971. Fanning Island expedition--1970. Pac. Sci. 25:188-190.

CROMWELL, T.

1951. Mid-Pacific oceanography, January through March 1950. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 54, 9 p.

1953. Circulation in a meridional plane in the central equatorial Pacific. J. Mar. Res. 12:196-213.

1954. Mid-Pacific oceanography II, transequatorial waters, June-August 1950, January-March 1951. In U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 131, 13 p., + figs. and station data.

CROMWELL, T., R. B. MONTGOMERY, and E. D. STROUP.

1954. Equatorial undercurrent in Pacific Ocean revealed by new methods. Science (Wash. D.C.) 119:648-649.

HELFRICH, P.

1973. The feasibility of brine shrimp production on Christmas Island. Univ. Hawaii, Sea Grant Publ. TR-73-02, 173 p.

HIDA, T. S., and J. E. KING.

1955. Vertical distribution of zooplankton in the central equatorial Pacific, July-August 1952. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 144, 22 p.

IKEHARA, I. I.

1953. Live-bait fishing for tuna in the central Pacific. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 107, 20 p.

IVERSEN, E. S., and G. I. MURPHY.

1955. What the Jangaard longline venture found in the mid-Pacific. Pac. Fisherm. 53(4):22, 25, 27.

IVERSEN, E. S., and H. O. YOSHIDA.

1956. Longline fishing for tuna in the central equatorial Pacific, 1954. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 184, 33 p.

1957. Longline and troll fishing for tuna in the central equatorial Pacific. January 1955 to February 1956. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 203, 38 p.

JENKIN, R. N., and M. A. FOALE.

1968. An investigation of the coconut-growing potential of Christmas Island. Ministry of Overseas Development, Land Resources Division, Directorate of Overseas Surveys, Tolworth, Surrey, England. Land Resources Study 4, Vol. 1. The environment and the plantations, 123 p. Vol. 2. Appendixes, A63.

JOSEPH J., and T. P. CALKINS.

1969. Population dynamics of the skipjack tuna (Katsuwonus pelamis) of the eastern Pacific Ocean. Inter-Am. Trop. Tuna Comm. 13:1-273.

JUNE, F. C.

1951. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part II - Notes on the tuna and bait resources of the Hawaiian, Leeward, and Line Islands. Commer. Fish. Rev. 13(1): 1-22.

JUNE, F. C., and J. W. REINTJES.

1953. Common tuna-bait fishes of the central Pacific. U.S. Fish Wildl. Serv., Res. Rep. 34, 54 p.

KING, J. E., and J. DEMOND.

1953. Zooplankton abundance in the central Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 54:111-144.

KING, J. E., and T. S. HIDA.

1957. Zooplankton abundance in the central Pacific. Part II. U.S. Fish Wildl. Serv., Fish. Bull. 118:365-395.

MCGARY, J. W., and T. M. NAITO.

1957. Wind atlas of the North Pacific. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 243, 35 p.

MCKERNAN, D. L.

1953. Pioneer longlining for tuna along the equator. Pac. Fisherm. 51(8):19, 21, 23.

MURPHY, G. I., and I. I. IKEHARA.

1955. A summary of sightings of fish schools and bird flocks and of trolling in the central Pacific. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 154, 19 p.

MURPHY, G. I., and E. L. NISKA.

1953. Experimental tuna purse seining in the central Pacific. Commer. Fish. Rev. 15(4):1-12.

MURPHY, G. I., and T. OTSU.

1954. Analysis of catches of nine Japanese tuna longline expeditions to the western Pacific. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 128, 46 p.

MURPHY, G. I., and R. S. SHOMURA.

1952. New tuna source. Pan-Am. Fisherm. 6(10):14-16.

1953a. Longline fishing for deep-swimming tunas in the central Pacific, 1950-51. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 98, 47 p.

1953b. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1952. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 108, 32 p.

1955. Longline fishing for deep-swimming tunas in the central Pacific, August-November 1952. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 137, 42 p.

1972. Pre-exploitation abundance of tunas in the equatorial central Pacific. Fish. Bull., U.S. 70:875-913.

SCHOTT, G.

1935. Geographie des Indischen und Stillen Ozeans. C. Boysen, Hamburg, 413 p.

SEELYE, C. J.

1950. Rainfall and its variability over the central and southwestern Pacific. N.Z. J. Sci. Technol., Sect. B, 32(2):11-24.

SETTE, O. E.

1955. Consideration of mid-ocean fish production as related to oceanic circulatory systems. J. Mar. Res. 14:398-414.

SETTE, O. E., and STAFF OF POFI.

1954. Progress in Pacific Oceanic Fishery Investigations 1950-53. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 116, 75 p.

SHOMURA, R. S., and G. I. MURPHY.

1955. Longline fishing for deep-swimming tunas in the central Pacific, 1953. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 157, 70 p.

SMITH, O. R., and M. B. SCHAEFER.

1949. Fishery exploration in the western Pacific (January to June, 1948, by vessels of the Pacific Exploration Company). Commer. Fish. Rev. 11(3):1-18.

TESTER, A. L.

1956. Recent equatorial tuna research. Pan-Am. Fisherm. 10(8):10-11, 21.

TUDOR, J. (editor).

1972. Pacific islands year book. 11th ed. Pacific Publications, Sydney, 542 p.

[U.S.] Bureau of Commercial Fisheries.

1963. Skipjack - A world resource. U.S. Fish Wildl. Serv., Circ. 165, 28 p.

U.S. FISH AND WILDLIFE SERVICE.

1955. Pacific Oceanic Fishery Investigations - Progress in 1954. Prepared for Tuna Industry Advisory Committee Meeting. Terminal Island, CA., 5-7 April 1955, 26 p. (Mimeogr.)

U.S. NAVY HYDROGRAPHIC OFFICE.

1944. World atlas of sea surface temperature charts. Second ed., H. O. No. 225.

1950. Atlas of surface currents. Northwestern Pacific Ocean. First ed., H. O. 569.

1959. Marine climatic atlas of the world. Vol. V, South Pacific Ocean, 267 charts. U.S. Govt. Print. Off., Wash., D.C.

U.S. WEATHER BUREAU.

1938. Atlas of climatic charts of the oceans. WB No. 1247. U.S. Govt. Print. Off., Wash., D.C., p. I-VI, 130 charts.

WALDRON, K. D.

1964. Fish schools and bird flocks in the central Pacific Ocean, 1950-61. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 464, 20 p.

YUEN, H. S. H., and J. E. KING.

1953. Sampan from Hawaii makes visit to Line Islands. Pan-Am. Fisherm. 7(12):10-11, 22.

TEXT FOOTNOTES

[2]Throughout this report, distances are given in kilometers followed by their equivalent in statute miles over land and nautical miles over the ocean.

[3]Barkley, R. A. 1962. A review of the oceanography of the central Pacific Ocean in the vicinity of the Line Islands. Unpublished report. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[4]For explanation of numerals and symbols in the charts, see Appendix.

[5]Naughton, J. J. Bird flock and surface tuna school sightings in the central Pacific Ocean, 1950-72. Southwest Region, National Marine Fisheries Service, NOAA, Honolulu, HI 96812. Manuscript in preparation.

[6]Uchida, R. N. Undated. A summary report on baiting and bait surveys by NMFS vessels in the Line Islands. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[7]Fish lengths, grouped and reported in intervals of 5 cm, were converted to weights in kilograms and pounds.

SURFACE CURRENTS AND TEMPERATURES

SOURCE OF INFORMATION

The information relating to monthly surface currents shown on this chart was compiled from observations made during the month for all years prior to 1935 by the co-operating observers of the Hydrographic Office. Observations were not considered reliable where tidal currents prevailed; where winds, sea, or swell of force 6 or above were recorded; where the vessel's draft or trim would cause excessive leeway; or when doubt existed as to the meaning of the entry "Nil" on the current report. All current calculations are based on the MEDIAN POSITION method; namely, each observation is applied at only one point, that point being midway between the beginning and end of the ship's run for which the current observation was made.

RESULTANT CURRENTS

The black arrows and numerals show the mean direction and force of the surface current in each 1-degree quadrangle for the month under average normal conditions. The accuracy of the resultant current in any quadrangle is necessarily determined by the number of observations used in the computation. The Hydrographic Office considers a resultant to be fairly accurate if computed from five or more observations in an area of 3,600 square miles. But on this chart all reliable information is shown, for the benefit of the navigator, even where less than the desired five observations were obtained.

The resultant currents in each 1-degree quadrangle are shown as follows:

The number in the upper right hand corner of the quadrangle represents the total current observations used in the computation. The numerals in the lower left hand corner of the quadrangle give the resultant drift in miles per day to the nearest tenth of a mile. The direction of the arrow in the center of the quadrangle shows the resultant set.

PREVAILING CURRENTS

The current roses ~~[shown in green on this chart]~~ were computed from the same information as the 1-degree resultants shown in black. The eight-point rose presents a graphical picture of the frequency of direction and the average drifts within the directions for each area outlined by the heavy brown lines.

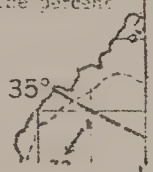
The arrows point in the direction towards which the current sets. When the frequency of direction is less than 5 percent, no arrow is shown. The length of the arrow, from the base of the arrow head to the inner edge of the circle, when placed on the attached frequency scale gives the number of times in each 100 observations that the current has been setting in or near the indicated direction. In instances where the full length of the arrow cannot be shown, the shaft is broken and the true percentage inserted in numerals within the break. The width of the shaft when placed on the attached drift scale gives the average drift in knots. The numeral in the center circle gives the percent of "nils" (no appreciable current observed). The approximate number of observations from which the current rose was computed can be obtained by adding the number of observations within the 1-degree quadrangles covered by the rose.

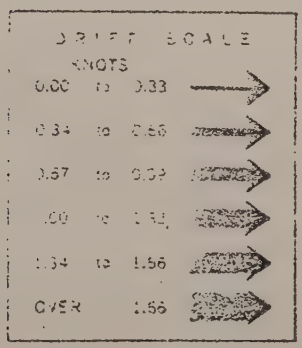
For example the attached rose should be read as follows:

Of the currents observed; 5 percent were setting northeast, the average drift was between 0.33 and 0.66 of a knot; 5 percent were setting east, the average drift was between 0.33 and 0.66 of a knot; 9 percent were setting southeast, the average drift was less than 0.33 of a knot; 5 percent were setting south, the average drift was between 1.33 and 1.66 knots; 57 percent were setting west, the average drift was between 0.67 and 1 knot; 5 percent were setting northwest, the average drift was less than 0.33 of a knot. The percent of "nils" was zero.

SEA TEMPERATURES

The monthly mean sea surface 5-degree isotherms ~~[shown in MAGENTA]~~ were compiled from the same source and for the same period as the resultant currents shown on this chart.





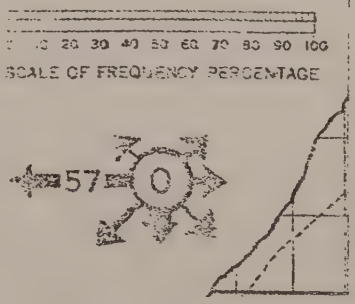


Table 1.--Minimum time and fetch required for winds to produce waves of a given height, and length of the resulting waves (adapted from McGary and Naito 1957 by BCF 1963).

TO PRODUCE WAVES	WIND VELOCITY														
	20 KNOTS			25 KNOTS			30 KNOTS			35 KNOTS			40 KNOTS		
	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)
4 FEET HIGH	3.2	11	40	2.0	7	43	1.3	< 5	46	1.0	< 5	49	0.9	< 5	50
8 FEET HIGH	19.0	120	155	6.2	26	86	4.0	18	82	3.0	14	86	2.2	11	86
12 FEET HIGH				20.0	745	216	8.0	48	133	5.4	31	123	4.0	22	125
16 FEET HIGH							16.2	125	237	8.9	59	172	6.3	42	166
20 FEET HIGH										14.0	120	258	9.1	67	216
24 FEET HIGH										31.0	320	462	13.4	115	298
28 FEET HIGH													20.9	210	405
32 FEET HIGH													36.5	440	620

Table 2.-- Surface wind summaries for years with extreme rainfall at Malden Island (from Seelye 1950).

Year commencing	Rainfall	Percentage wind frequency								
		N	NE	E	SE	S	SW	W	NW	Calm
	Inch									
May 1914	100.30	11	17	38	11	1	1	3	6	12
April 1924	6.84	0	7	88	4	0	0	0	0	1

Table 3.--The average annual rainfall, its variability, and the percentage frequency of dry months at Fanning and Malden Islands (from Seelye 1950).

Island	Annual rainfall		Percentage frequency of dry months				
	Average	Variability	Summer	Autumn	Winter	Spring	Year
	Inches	Percent	Percent	Percent	Percent	Percent	Percent
Fanning	84	41	46	15	15	45	30
Malden	28	67	68	39	42	58	52

Table 4.--Mean, highest and lowest monthly and annual rainfall for the period 1903-66 at London, Christmas Island, in millimeters (from Jenkin and Foale 1968).

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mean 23 years	72	80	118	163	86	75	74	32	32	18	21	42	813
Mean 33 years	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	873
Highest monthly	575	671	482	539	291	283	199	164	203	98	117	347	2 621*
Lowest monthly	0	1	0	8	1	0	0	1	0	0	0	0	177**

* highest annual rainfall, 1941 ** lowest annual rainfall, 1954 n.a. = not available

Table 5.--Summary of monthly temperature data for London, Christmas Island 1953-65 in °C and °F (from Jenkin and Foale 1968).

Data	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Temperatures	°C												
Mean monthly 0800 h	26.6	26.7	27.0	27.2	28.0	27.5	27.5	27.0	27.6	27.7	27.3	26.8	27.2
Mean monthly 1400 h	29.4	29.3	30.1	29.7	30.6	30.2	30.1	29.6	30.3	30.3	30.1	29.4	29.9
Mean monthly 2000 h	25.9	25.9	26.1	26.1	27.0	26.5	26.5	25.9	26.3	26.2	26.0	25.7	26.1
Mean monthly maximum	30.0	30.0	30.4	30.3	30.7	30.6	30.3	30.5	30.4	30.4	30.5	30.0	30.3
Mean monthly minimum	24.4	24.3	24.7	24.9	25.0	24.8	24.6	24.8	24.6	24.5	24.4	24.3	24.6
Highest monthly maximum	33.3	32.3	32.8	33.3	33.3	33.3	32.8	33.3	33.3	33.3	35.0	36.7	36.7
Lowest monthly minimum	21.8	21.8	21.7	21.1	21.7	20.8	21.3	22.1	22.8	22.2	21.1	21.1	20.8
Mean monthly*	27.2	27.2	27.5	27.6	27.8	27.7	27.4	27.7	27.5	27.5	27.4	27.1	27.4
Temperatures	°F												
Mean monthly 0800 h	79.9	80.0	80.6	81.0	82.4	81.5	81.5	80.6	81.7	81.9	81.1	80.2	81.0
Mean monthly 1400 h	85.0	84.7	86.2	85.5	87.1	86.3	86.2	85.2	86.6	86.5	86.1	85.0	85.9
Mean monthly 2000 h	78.6	78.7	78.9	79.0	80.6	79.7	79.7	78.7	79.3	79.1	78.8	78.2	79.1
Mean monthly maximum	86.1	86.0	86.7	86.5	87.2	87.1	86.6	86.8	86.7	87.0	86.6	86.0	86.6
Mean monthly minimum	75.9	75.8	76.4	76.7	77.1	76.6	76.3	76.7	76.3	76.0	76.0	75.7	76.3
Highest monthly maximum	92.0	90.0	91.0	92.0	92.0	92.0	91.0	92.0	92.0	92.0	95.0	98.0	98.0
Lowest monthly minimum	70.0	71.2	71.0	70.0	71.0	69.4	70.3	71.1	73.0	71.9	70.0	70.0	69.4
Mean monthly*	81.0	80.9	81.5	81.7	82.1	81.9	81.4	81.8	81.5	81.5	81.3	80.8	81.5

* ½ (mean monthly maximum + mean monthly minimum)

Table 6.--Average mean monthly and annual atmospheric pressure at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in millibars (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
0800	1010.0	1010.0	1010.2	1009.7	1009.8	1010.2	1010.2	1010.1	1010.4	1010.7	1010.4	1010.2	1010.2
1400	1007.4	1007.4	1008.1	1007.7	1008.0	1008.4	1008.7	1008.4	1008.3	1008.1	1007.5	1007.3	1007.9
2000	1008.9	1008.7	1009.2	1008.7	1009.0	1009.5	1009.4	1009.3	1009.6	1009.7	1009.3	1008.9	1009.2

Table 7.--Average mean monthly and annual relative humidity at 0800, 1400, and 2000 h (local time) and for the whole day at London, Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
0800	77.3	78.4	79.8	80.4	76.5	75.4	76.2	73.8	71.3	70.5	71.4	74.8	75.5
1400	62.0	63.4	65.1	68.2	64.1	62.7	63.1	59.2	59.3	58.8	58.5	61.0	62.1
2000	81.3	81.7	83.9	84.4	80.8	79.9	78.9	77.6	77.6	77.3	77.6	79.1	80.0
Day*	71.7	74.7	74.6	73.6	72.5	71.2	71.2	68.5	68.5	68.0	68.0	70.2	71.1

* ½ (mean monthly relative humidity at 1400 h + mean monthly relative humidity at 2000 h)

Table 8.--Average mean monthly and annual cloud cover at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in oktas and tenths (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	Oktas												
0800	3.8	3.8	4.2	4.5	3.7	3.6	3.7	3.4	3.4	3.5	3.8	3.8	3.8
1400	4.1	4.1	4.3	4.7	4.0	3.9	4.1	3.7	3.5	3.9	3.8	4.2	4.0
2000	3.0	3.0	3.3	3.6	2.9	2.9	2.9	2.7	2.6	2.8	2.6	2.9	2.9
	Tenths												
0800	4.8	4.7	5.2	5.6	4.6	4.5	4.6	4.3	4.3	4.4	4.8	4.7	4.7
1400	5.2	5.1	5.4	5.9	5.0	4.9	5.1	4.6	4.4	4.9	4.8	5.3	5.1
2000	3.7	3.8	4.2	4.5	3.6	3.6	3.6	3.4	3.3	3.5	3.3	3.6	3.7

Table 9.--Mean monthly sunshine in hours per day at London, Christmas Island (from Jenkin and Foale 1968).

Year	J	F	M	A	M	J	J	A	S	O	N	D
1953	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	8.3
1954	8.5	8.4	8.4	7.9	n.a.	8.4	8.3	8.7	8.9	8.7	8.2	8.3
1955	7.9	8.4	8.0	8.2	8.5	8.5	8.3	8.9	8.8	8.4	8.0	8.2
1956	8.8	9.1	8.0	8.2	9.4	9.0	9.6	9.7	9.1	9.4	9.2	9.5
1957	9.5	9.5	9.7	9.0	9.0	9.1	8.7	10.0	9.5	9.7	9.0	8.3
1958	8.3	9.0	9.2	9.0	8.9	9.6	9.5	9.5	10.0	9.8	9.7	9.5
1959	9.8	9.2	9.5	8.9	9.7	9.3	9.3	10.0	9.9	9.8	10.1	10.3
1960	10.3	10.1	10.3	9.8	10.3	10.3	10.4	10.6	10.7	11.1	10.6	11.0
1961	10.7	10.6	10.7	10.4	10.5	10.5	n.a.	10.9	n.a.	n.a.	10.8	n.a.
1962	n.a.	n.a.	n.a.	n.a	n.a.	n.a.	10.1	n.a.	10.6	n.a.	n.a.	n.a.
1963	n.a.	n.a.	10.1	8.9	9.9	9.7	9.1	9.0	9.6	9.0	8.7	8.7
1964	8.5	8.8	8.6	8.9	8.9	9.6	9.5	9.6	9.8	9.6	9.6	9.6
1965	9.9	10.2	9.4	9.8	9.6	9.4	9.5	9.2	10.0	9.9	n.a.	n.a.
Average	9.2	9.3	9.3	9.0	9.5	9.4	9.3	9.6	9.7	9.5	9.4	9.2

Table 10.--Mean monthly and annual wind speed at 0800, 1400, and 2000 h (local time) and for the whole day in meters per second (m/s) and knots (kn) at Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	m/s												
0800	4.4	4.1	4.0	3.7	3.7	3.6	4.0	4.5	4.3	4.2	4.5	4.4	4.1
1400	5.3	4.9	4.8	4.4	4.3	4.4	4.7	4.9	4.6	4.5	4.8	4.8	4.7
2000	4.6	4.2	3.9	3.5	3.7	3.6	3.9	4.4	4.3	4.3	4.4	4.6	4.1
Day *	4.9	4.5	4.3	4.0	4.0	4.0	4.3	4.7	4.5	4.4	4.6	4.7	4.4
	kn												
0800	8.5	8.0	7.7	7.1	7.2	7.0	7.7	8.7	8.4	8.2	8.7	8.5	8.0
1400	10.2	9.6	9.3	8.5	8.4	8.6	9.1	9.6	9.0	8.8	9.3	9.3	9.1
2000	8.9	8.1	7.5	6.8	7.1	7.0	7.5	8.5	8.4	8.4	8.5	8.9	8.0
Day *	9.6	8.8	8.4	7.7	7.8	7.8	8.3	9.1	8.7	8.6	9.0	9.1	8.6

* ½ (mean monthly wind speed at 1400 h + mean monthly wind speed at 2000 h)

Table 11.--Average volumes and night-day ratios of zooplankton collected by Clarke-Bumpus samplers on Hugh M. Smith cruise 16 for three depths of sampling, July-August 1952 (from Hida and King 1955).

Depth	Time of hauling	No. of samples	Avg. volume, cc/1000m^3	Ratio, N/D
Surface	Night	11	85.2	1.63
	Day	13	52.3	
Intermediate	Night	7	27.6	.90
	Day	9	30.7	
Deep	Night	6	12.5	.66
	Day	9	19.0	

Table 12.--Summary of island observations on fish schools and bird flocks, 1950-53 (from Murphy and Ikehara 1955).

Locality	Period	Number of days		Yellowfin		Skipjack		Mixed[1]		Unidentified		Total fish schools		Bird flocks	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	26	6	16	0.5	0	0.0	2	0.1	15	0.5	33	1.0	33	1.0
	June-Aug.	4	3	13	1.9	1	0.1	4	0.6	3	0.4	21	3.0	27	3.9
	Sept.-Nov.	22	11	20	0.6	12	0.4	4	0.1	55	1.7	91	2.8	108	3.3
	Dec.-Feb.	8	19	7	0.3	4	0.1	3	0.1	24	0.9	38	1.4	71	2.6
Total and average[2]		60	39	56	0.8	17	0.2	13	0.2	97	0.9	183	2.1	239	2.7
Phoenix Is.	Mar.-May	-	3	0	0.0	0	0.0	0	0.0	2	0.7	2	0.7	6	2.0
	June-Aug.	3	4	8	1.1	6	0.9	0	0.0	5	0.7	19	2.7	26	3.7
	Sept.-Nov.	0	2	3	1.5	2	1.0	0	0.0	2	1.0	7	3.5	1	0.5
	Dec.-Feb.	3	14	3	0.2	1	0.1	0	0.0	5	0.3	9	0.5	13	0.8
Total and average[2]		6	23	14	0.7	9	0.5	0	0.0	14	0.7	37	1.9	46	1.8
Hawaiian Is.	Mar.-May	0	9	0	0.0	7	0.8	0	0.0	7	0.8	14	1.6	18	2.0
	June-Aug.	33	15	4	0.1	81	1.7	0	0.0	20	0.4	105	2.2	100	2.1
	Sept.-Nov.	4	31	0	0.0	17	0.5	0	0.0	21	0.6	38	1.1	47	1.3
	Dec.-Feb.	0	4	1	0.2	1	0.2	0	0.0	1	0.2	3	0.8	3	0.8
Total and average[2]		37	59	5	0.1	106	0.8	0	0.0	49	0.5	160	1.4	168	1.6
Leeward Is.	Mar.-May	1	4	1	0.2	3	0.6	0	0.0	25	5.0	29	5.8	47	9.4
Jarvis I.	June-Aug.	1	0	2	2.0	0	0.0	0	0.0	1	1.0	3	3.0	4	4.0
	Dec.-Feb.	1	1	0	0.0	0	0.0	0	0.0	3	1.5	3	1.5	4	2.0
Malden I.	Sept.-Nov.	1	0	0	0.0	2	2.0	0	0.0	4	4.0	6	6.0	6	6.0
Starbuck I.	Dec.-Feb.	1	0	0	0.0	3	3.0	0	0.0	0	0.0	3	3.0	3	3.0
Johnston I.	Mar.-May	0	2	0	0.0	0	0.0	0	0.0	5	2.5	5	2.5	8	4.0
Marquesas Is.	June-Aug.	0	2	0	0.0	2	1.0	0	0.0	0	0.0	2	1.0	3	1.5
Samoa Is.	Dec.-Feb.	0	1	0	0.0	2	2.0	0	0.0	7	7.0	9	9.0	9	9.0
Nukunono Is.	Dec.-Feb.	0	1	0	0.0	0	0.0	0	0.0	1	1.0	1	1.0	1	1.0

[1] Yellowfin and skipjack tunas.

[2] Unweighted averages.

Table 13.--Summary of semioceanic observations associated with particular island groups,[1] 1950-53 (from Murphy and Ikehara 1955).

Locality	Period	Number of days		Yellowfin		Skipjack		Unidentified		Total fish schools		Bird flocks		Number of birds[2]	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	1	1.0	30	30.0
	June-Aug.	0	2	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	37	18.5
	Sept.-Nov.	0	3	1	0.3	2	0.7	6[3]	2.0	9	3.0	12	4.0	162	54.0
	Dec.-Feb.	0	17	0	0.0	10	0.6	21	1.2	31	1.8	36	2.1	959	56.4
Total and average[4]		0	23	1	0.1	13	0.6	27	0.8	41	1.4	50	1.9	1188	39.7
Phoenix Is.	Mar.-May	0	4	0	0.0	1	0.2	4	1.0	5	1.2	8	2.0	310	77.5
	June-Aug.	0	2	2	1.0	3	1.5	1	0.5	6	3.0	13	6.5	615	307.5
	Sept.-Nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dec.-Feb.	0	4	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2	43	10.8
Total and average[4]		0	10	2	0.3	4	0.6	5	0.5	11	1.4	22	2.9	968	131.9
Hawaiian Is.	Mar.-May	0	10	0	0.0	3	0.3	5	0.5	8	0.8	12	1.2	558	55.8
	June-Aug.	1	8	0	0.0	4	0.4	10	1.1	14	1.6	19	2.1	1212	134.7
	Sept.-Nov.	0	16	0	0.0	10	0.6	7	0.4	17	1.1	16	1.0	1283	80.2
	Dec.-Feb.	0	7	0	0.0	1	0.1	1	0.1	2	0.3	3	0.4	144	20.6
Total and average[4]		1	41	0	0.0	18	0.4	23	0.5	41	1.0	50	1.2	3197	72.8
Leeward Is.	Mar.-May	0	2	0	0.0	2	1.0	1	0.5	3	1.5	3	1.5	85	42.5
Jarvis I.	Sept.-Nov.	0	1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	35	35.0
	Dec.-Feb.	0	2	0	0.0	2	1.0	0	0.0	2	1.0	8	4.0	352	176.0
Malden I.	June-Aug.	0	1	0	0.0	1	1.0	0	0.0	1	1.0	3	3.0	94	94.0
Starbuck I.	Sept-Nov.	0	1	0	0.0	0	0.0	2	2.0	2	2.0	2	2.0	86	86.0
	Dec.-Feb.	0	5	0	0.0	2	0.4	17	3.4	19	3.8	22	4.4	1172	234.4
Johnston I.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	2	2.0	11	11.0
Marquesas Is.	Mar.-May	0	1	0	0.0	0	0.0	0	0.0	0	0.0	1	1.0	16	16.0
	June-Aug.	0	4	0	0.0	1	0.2	3	0.8	4	1.0	5	1.2	309	77.2
Samoa - Nukunono Is.	Dec.-Feb.	0	3	0	0.0	0	0.0	2	0.7	2	0.7	2	0.7	12	4.0

1/ Semioceanic observations were considered to be from 60 to 180 miles from the islands.

2/ Includes scattered birds.

3/ Two schools of little tunny.

4/ Unweighted averages.

Table 14.--Total scouting hours and rate of sighting of bird flocks, skipjack tuna schools, and total schools in the 5° square bounded by lat. 0° and 5°N and by long. 155° and 160°W (data extracted from Naughton, see footnote 5).

Month	Total scouting hours		Sightings per 10 h of scouting					
			Bird flocks		Skipjack tuna schools		Total schools	
	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72
December-February	402	553	2.96	2.84	0.32	0.30	1.37	1.62
March-May	304	560	1.91	2.45	0.26	0.30	0.59	1.70
June-August	104	150	3.27	6.47	0.00	1.13	0.29	4.60
September-November	619	412	2.92	5.63	0.53	0.97	1.52	3.32

Note: The total scouting hours in September-November 1950-61 are higher than in 1950-72 because of adjustments made by Naughton eliminating some of the hours of darkness when no scouting was conducted.

Table 15.--Results of baiting operations in the Line Islands (data extracted from Table 1, Ikehara 1953).

Locality	Date	Number of days[1]	Number of sets		Catch (by buckets)		Species of bait	
			Beach seine	Night lift net	Beach seine	Night lift net	Beach seine	Night lift net
Line Islands:								
Palmyra Island	June 1951; August 1950	2	5	1	115	0	100% mullet	--
Christmas Island	June 1951	1	5	0	52	--	100% mullet	--
Kingman Reef	August 1950	1	0	1	--	0	--	--
Fanning Island	June 1951	1	0	0	--	--	--	--

[1]This includes only days or nights when bait fishing and/or scouting was carried on.

Table 14.--Total scouting hours and rate of sighting of bird flocks, skipjack tuna schools, and total schools in the 5° square bounded by lat. 0° and 5°N and by long. 155° and 160°W (data extracted from Naughton, see footnote 5).

Month	Total scouting hours		Sightings per 10 h of scouting					
			Bird flocks		Skipjack tuna schools		Total schools	
	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72
December-February	402	553	2.96	2.84	0.32	0.30	1.37	1.62
March-May	304	560	1.91	2.45	0.26	0.30	0.59	1.70
June-August	104	150	3.27	6.47	0.00	1.13	0.29	4.60
September-November	619	412	2.92	5.63	0.53	0.97	1.52	3.32

Note: The total scouting hours in September-November 1950-61 are higher than in 1950-72 because of adjustments made by Naughton eliminating some of the hours of darkness when no scouting was conducted.

Table 15.--Results of baiting operations in the Line Islands (data extracted from Table 1, Ikehara 1953).

Locality	Date	Number of days[1]	Number of sets		Catch (by buckets)		Species of bait	
			Beach seine	Night lift net	Beach seine	Night lift net	Beach seine	Night lift net
Line Islands:								
Palmyra Island	June 1951; August 1950	2	5	1	115	0	100% mullet	--
Christmas Island	June 1951	1	5	0	52	--	100% mullet	--
Kingman Reef	August 1950	1	0	1	--	0	--	--
Fanning Island	June 1951	1	0	0	--	--	--	--

[1]This includes only days or nights when bait fishing and/or scouting was carried on.

Table 16.--Summary of baiting operations in the Line Islands, 1955-64.

Date	Cruise	Locality	Species	Size	Sets	Catch	Catch/set
				Cm	No.	Bucket	Bucket
Jan. 31-Feb. 13, 1955	CHG-19	Palmyra, Fanning, and Christmas	Mullet, *Mugil longimanus*	--	16	106	6.6
Jan. 7, 1958	CHG-42	English Harbor at Fanning	Mostly mullet; some goatfish and milkfish	7.6-20.3	7	66	9.4
Nov. 11, 1958	CHG-42	Palmyra	Mostly mullet; some goatfish and milkfish	7.6-20.3	7	133	19.0
Oct. 21, 1960	CHG-50	Strawn Island on Palmyra	Mullet	5.1-20.3	6	33	5.5
Oct. 25, 1960	CHG-50	English Harbor at Fanning	Mostly mullet; some goatfish and milkfish	5.1-20.3	5	55	11.0
Aug. 10, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	2	2.0
Aug. 11, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	2	2.0
Aug. 11, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	8	8.0
Oct. 17, 1964	CHG-76	Christmas	Mullet, goatfish, and mountain bass	7.6-15.2	3	50	16.7
Oct. 21, 1964	CHG-76	Palmyra	Mullet	5.1-10.2	2	48	24.0

Table 17.--Summary of bait survey, Charles H. Gilbert cruise 19.

Date 1955	Locality	Shoreline scouted (miles)	Number of buckets	
			Seen	Caught
Jan. 31	Strawn Island - Palmyra	0.4	5	0*
Jan. 31	Paradise Island - Palmyra	0.5	10	0*
Feb. 1	Along causeway and north shore of east lagoon - Palmyra	0.5	10	0*
Feb. 1	Strawn Island - Palmyra	0.2	3	3
Feb. 1	Kaula Island - Palmyra	0.1	50	30
Feb. 4	South of English Harbor - Fanning	0.9	2	0*
Feb. 4	North of English Harbor - Fanning	1.1	50	7
Feb. 5	700 yds. northwest of Cartwright Point - Fanning	0.4	50	24
Feb. 6	700 yds. northwest of Cartwright Point - Fanning	0.2	20	20
Feb. 7	Lagoon shore northeast side Tehenua Tepapa - Fanning	2.3	50	0*
Feb. 9	Cook Island southward - Christmas	4.5	5	5
Feb. 13	Paradise Island - Palmyra	0.3	40	17

*Did not attempt to catch.

Table 18.--Summary of the results of live-bait fishing for tunas in the Line Islands (data extracted from Table 2, Ikehara 1953).

Locality	Date	Number of hours fishing and scouting		Number of fish schools seen	Number of fish schools chummed	Number of tuna schools fished	Actual time spent fishing		Number of tuna caught	Total weight of tuna caught	Number of times sharks interfered
		H	Min				H	Min		Tons	
Line Islands											
Kingman Reef	Aug. 1950	11	20	3	3	1	0	13	13	0.13	1
Kingman Reef	May 1951	17	00	15	13	6	2	05	1,008	11.75	3
Palmyra Island	June 1951	J3	50	6	5	2	0	05	22	0.25	1
Washington Island	June 1951	15	05	8	7	2	0	33	191	2.62	3
Fanning Island	June 1951	5	05	4	4	4	0	34	327	4.09	0
Christmas Island	June 1951	9	00	3	3	2	1	07	970	10.46	1
Jarvis Island	June 1951	3	00	3	1	1	0	27	10	0.15	1
Total		64	20	42	36	18	5	04	2,541	29.45	10

Table 19.--Daily troll catches in the Line Islands, John R. Manning cruise 2, 1950 (from Bates 1950).

Date	Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
		No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
Apr. 22	Kingman Reef	5	9-1/2*	20	767	1	35	0.42	16.2	3
23	Do	5	10	79	2,665	2	70	1.58	53.3	5
24	Do	5	8	53	1,955	7	245	1.32	48.8	2
25	Do	5	9	59	1,666	5	175	1.31	37.0	0
26	Do	6	1-1/2	5	136	0	0	0.56	15.1	0
May 28	Do	6	2	15	475	6	175	1.25	39.6	0
29	Do	6	10	32	954	7	230	0.53	15.9	0
30	Do	6	10	49	1,592	8	225	0.82	26.6	0
31	Do	6	4-1/2	27	885	17	465	1.00	32.8	0
		[6]7	5-1/2	25	957	--	--	0.65	24.9	0
June 1	Do	7	7	6	239	8	245	0.12	4.9	0
2	Do	7	3	3	175	0	0	0.14	8.3	0
Totals and averages		5.9	80	373	12,466	60	1,865	0.79	26.4	10

Table 19.--Continued.

Date	Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
		No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
Apr. 27	Palmyra	6	10	95	1,941	4	140	1.58	32.4	4
28	Do	6	7*	17	319	5	165	0.40	7.6	0
29	Do	6	6*	6	192	0	0	0.17	5.3	0
May 1	Do	6	4*	0	0	0	0	0	0	0
27	Do	6	9-1/2	29	995	7	162	0.51	17.5	0
28	Do	6	3-1/4	18	385	6	185	0.92	19.7	1
June 2	Do	7	3	1	15	0	0	0.05	0.7	0
3	Do	7	5-1/2	17	476	4	130	0.44	12.3	0
4	Do	7	4-1/2	10	290	4	98	0.32	9.2	0
Totals and averages		6.35	52-3/4	193	4,613	30	880	0.58	13.8	5
May 3	Washington	6	11*	42	1,680	9	400	0.64	25.5	0
4	Do	6	10-1/2	42	1,504	15	600	0.67	23.9	0
5	Do	6	10*	16	680	4	140	0.27	11.3	[7]1
24	Do	6	7-1/2	41	1,314	1	40	0.91	29.2	0
June 5	Do	7	[8]9	22	843	17	440	0.35	13.3	0
6	Do	7	10-1/4	33	1,080	16	393	0.46	15.0	0
Totals and averages		6.34	58-1/4	196	7,101	62	2,013	0.53	19.3	1

Table 19.--Continued.

Date	Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
		No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
May 6	Fanning	6	1	3	120	0	0	0.50	20.0	0
8	Do	6	6*	2	66	0	0	0.06	1.8	0
9	Do	6	10	1	50	0	0	0.02	0.8	0
10	Do	6	5-1/2	0	0	0	0	0	0	1
11	Do	6	2-1/2	0	0	0	0	0	0	0
23	Do	6	4	0	0	0	0	0	0	0
June 7	Do	6	3-1/2	9	213	0	0	0.43	10.1	0
Totals and averages		6	32-1/2	15	449	0	0	0.08	2.3	1
May 12	Christmas	6	7-1/2	28	1,343	1	35	0.62	29.9	0
13	Do	[9]6	7-1/2	23	1,100	2	100	0.51	24.5	0
15	Do	6	11	5	237	5	206	0.08	3.6	0
16	Do	6	11*	5	239	1	45	0.08	3.6	0
17	Do	6	10-1/2	13	537	5	279	0.21	8.5	0
18	Do	6	5	9	405	3	105	0.30	13.5	0
19	Do	6	5	15	569	6	235	0.50	19.0	0
20	Do	6	4-1/2	7	260	3	125	0.26	9.6	0
Totals and averages		6	62	105	4,690	26	1,130	0.28	12.6	0

Table 19.--Continued.

[1]Includes hours trolled in circling islands on days starred (*).

[2]Yellowfin tuna, *Thunnus albacares*.

[3]Wahoo, *Acanthocybium solandri*.

[4]Skipjack tuna, *Katsuwonus pelamis*.

[5]Estimated weights.

[6]Seventh line added on May 31 just before noon.

[7]Little tunny or kawakawa (*Euthynnus* spp.).

[8]Commenced fishing after 0900 h.

[9]Seine set in morning--no trolling for 3-1/2 h.

Table 20.--Observations on five large schools of tuna sighted at Kingman Reef on John R. Manning cruise 2, 1950 (from Bates 1950).

Date	Species	Est. size of tuna	Est. size of school	
4/22	Yellowfin tuna	25-45 lb	at least 50 tons	Breezing,[1/] travelling slowly east to west in manner similar to Central American schools.
4/23	Yellowfin and skipjack tunas	--	50-60 tons	Breezing, travelling fast, mixed school
	Yellowfin tuna	--	large	Travelled 1/4 mile ahead of boat at all times.
4/25	Skipjack tuna	1-2 lb	large	Shiners,[2/] jumpers--appeared in 3 different schools during day.
5/29	Skipjack tuna	3-8 lb	very large	Breezing, some jumpers, off NW tip in 350-400 fathoms. Similar but smaller school sighted later in day.
5/30	Yellowfin tuna	15-60 lb mixed	small	Breezing, slow-moving. A second and similar school also seen on same day.

1/ Breezing is a term applied to a school of fish having the appearance of a wind disturbance or "tide rip" (e.g., a rippling effect).

2/ One indication of fish is observing their sides or bellies flashing or "shining" in the water as the fish turns partially over. Shiners can be seen at great depths and distances depending on type of fish and brightness of day.

NOTE: The behavior of tuna in the above table is as expressed by Captain Kursar as well as other west coast fishermen aboard with considerable fishing experience in Mexican and Central American waters. All comparative estimates of school sizes are also based on west coast tuna standards.

Table 21.--Number of yellowfin tuna caught by 2-h periods, John R. Manning cruise 2, 1950 (from Bates 1950).

Time	Kingman Reef-6 days[1]		Palmyra-3 days[1]		Washington-4 days[1]	
	No. of yellowfin tuna caught	Catch per 2-h period per day	No. of yellowfin tuna caught	Catch per 2-h period per day	No. of yellowfin tuna caught	Catch per 2-h period per day
0700-0900[2]	74	12.3	10	3.3	6	1.5
0900-1100	82	13.7	13	4.3	26	6.5
1100-1300	72	12.0	38	12.7	49	12.3
1300-1500[2]	39	6.5	32	10.7	38	9.5
1500-1700[2]	59	9.8	39	13.0	35	8.8

[1]Only data are used for full trolling days (between 0700 and 1700). Insufficient data are available for Fanning and Christmas Islands.

[2]Figures low during these hours only because fishing grounds were not reached without some scouting and were left earlier than 1700 on run to anchorage,

Table 22.--Results of trolling in island areas, 1950-53 (from Murphy and Ikehara 1955).

Species	Number caught, by locality											
	Line Islands	Phoenix Islands	Hawaiian Islands	Leeward Hawaiian Islands	Malden Island	Starbuck Island	Jarvis Island	Samoa Islands	Marquesas Islands	Nukunono Island	Johnston Island	Total
Primary trolling:												
TUNAS												
Yellowfin	241	34	-	1	7	11	29	-	-	-	-	323
Skipjack	5	0	-	0	0	0	0	-	-	-	-	5
Little tunny	0	0	-	0	0	0	0	-	-	-	-	-
Total	246	34	-	1	7	11	29	-	-	-	-	328
MISCELLANEOUS												
Dolphin	0	0	-	0	0	0	0	-	-	-	-	-
Wahoo	171	7	-	0	3	8	12	-	-	-	-	201
Jacks	11	0	-	0	1	0	0	-	-	-	-	12
Rainbow runner	8	0	-	0	0	0	0	-	-	-	-	8
Others	24	0	-	0	1	0	0	-	-	-	-	25
Total	214	7	-	0	5	8	12	-	-	-	-	246
Grand Total	460	41	-	1	12	19	41	-	-	-	-	574
Line hours	890	79	-	13	14	20	12	-	-	-	-	1,028
Tuna/100 line hours	27.6	43.0	-	7.7	50.0	55.0	241.7	-	-	-	-	31.9
All species/100 line hours	51.5	51.8	-	7.7	85.6	95.0	341.7	-	-	-	-	55.8
Secondary trolling:												
TUNAS												
Yellowfin	34	1	3	0	0	0	0	0	0	0	3	41
Skipjack	1	0	6	0	0	0	0	0	0	0	0	7
Little tunny	0	0	1	7	0	0	0	0	0	0	0	8
Total	35	1	10	7	0	0	0	0	0	0	3	56
MISCELLANEOUS												
Dolphin	0	0	11	2	0	0	0	1	0	0	0	14
Wahoo	17	3	2	1	0	0	0	0	0	0	0	23
Jacks	1	0	0	0	0	0	0	0	0	0	0	1
Rainbow runner	2	0	0	0	0	0	0	0	0	0	0	2
Others	2	0	0	0	0	0	0	0	0	0	0	2
Total	22	3	13	3	0	0	0	1	0	0	0	42
Grand total	57	4	23	10	0	0	0	1	0	0	3	98
Line hours	739	339	930	173	8	10	46	29	22	32	56	2,384
Tuna/100 line hours	4.7	0.3	1.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	2.3
All species/100 line hours	7.7	1.2	2.5	5.8	0.0	0.0	0.0	3.4	0.0	0.0	5.4	4.1

Table 23.--Results of trolling in the Line Islands (from Iversen and Yoshida 1957).

Time	Hours trolled	Yellowfin tuna	
		Number	Catch per hour
April to June 1950 (Bates 1950)	285.5	882	3.1
October 1950 to April 1953 (Murphy and Ikehara 1955)	[1]178.0	241	1.4
March 1955 to February 1956	766.5	946	1.2

[1]Murphy and Ikehara (1955) reported 890 line-hours of trolling using 4-6 lines. The number of hours trolled was obtained by dividing 890 line-hours by five, the average number of lines trolled.

Table 24.--Species of fish listed by Murphy and Shomura (1972) as likely to be captured by trolling or observed near the surface in the central equatorial Pacific Ocean (from Helfrich 1973).

Albacore, *Thunnus alalunga* (Bonnaterre)
Barracuda, *Sphyraena barracuda* (Walbaum)
Bigeye tuna, *Thunnus obesus* (Lowe)
Blue marlin, *Makaira ampla* (Poey)
Bonita shark, *Isurus glaucus* (Muller and Henle)
Broadbill swordfish, *Xiphias gladius* (Linnaeus)
Common dolphin, *Corphaena hippurus* (Linnaeus)
Great blue shark, *Prionace glauca* (Linnaeus)
Lancetfish, *Alepisaurus* sp.
Sailfish, *Istiophorus platypterus* (Shaw and Nodder)
Shortnose spearfish, *Tetrapturus angustirostris* (Tanaka)
Silky shark, *Eulamia floridanus* (Bigelow, Schroeder & Springer)
Skipjack tuna, *Katsuwonus pelamis* (Linnaeus)
Striped marlin, *Makaira audax* (Philippi)
Wahoo, *Acanthocybium solandri* (Cuvier & Valenciennes)
White marlin, *Istiompax marlina* (Jordan and Hill)
Whitetip shark, *Pterolamiops longimanus* (Poey)
Yellowfin tuna, *Thunnus albacares* (Bonnaterre)
Rainbow runner, *Elagatis bipinnulatus*
Crevalles (Jacks), *Caranx melampygus*

Table 25.--Number of tuna, marlin, shark, and other species caught on longline gear on exploratory fishing cruises to the central equatorial Pacific Ocean, 1950-5

Vessel name	Cruise No.	Yellowfin tuna	Bigeye tuna	Albacore	Skipjack tuna	Marlin	Shark	Others
		No.	No.	No.	No.	No.	No.	No.
Hugh M. Smith	[1]5	71	--	4	--	6	55	--
	[1]7	183	22	--	5	19	94	30
	[1]11	95	23	5	10	5	31	14
	[2]18	59	50	1	14	21	170	56
	[3]19	174	1	--	1	4	78	8
John R. Manning	[4]11	211	30	64	17	20	153	19
	[2]12	144	28	2	8	11	77	34
	[2]13	148	28	21	33	19	170	34
	[3]14	294	45	40	29	45	148	40
	[3]15	277	57	101	24	24	198	35
	[3]16	466	51	31	14	28	233	50
	[3]17	149	6	4	4	8	52	5
	[3]18	171	8	2	6	6	183	28
	[5]20	425	17	7	8	13	415	17
	[6]24	128	4	--	2	9	131	9
	[6]27	158	5	--	2	3	155	9
	[6]28	21	--	--	3	1	73	8
	[6]29	169	9	--	7	9	222	9
Charles H. Gilbert	[4]1	72	43	--	--	8	64	20
	[5]15	218	78	13	18	26	409	51
	[6]20	246	1	--	3	7	182	6
	[6]25	23	1	--	5	3	37	7
Cavalieri	[2]1	720	65	--	29	18	195	105
North American	[5]1	1,440	13	13	20	13	369	31
	[5]2	1,730	8	11	77	41	513	19
Alrita	[5]1	1,338	12	14	11	9	481	4
	[5]2	689	7	9	22	16	216	3

Table 25.--Continued.

Vessel name	Cruise No.	Yellowfin tuna	Bigeye tuna	Albacore	Skipjack tuna	Marlin	Shark	Others
		No.	No.	No.	No.	No.	No.	No.
Oceanic	[5]1	59	2	--	--	4	151	1
	[5]2	104	1	--	3	--	85	2
Brothers	[5]1	117	--	--	--	4	140	--
	[5]2	36	1	--	2	1	45	1
Sea Hawk	[5]1	58	--	--	3	9	136	1
Commonwealth	[5]1	99	7	1	9	5	87	6
	[5]2	178	2	--	2	10	191	3
	[6]3	40	6	--	2	3	53	2
	[6]4	137	4	--	4	5	114	1
	[6]5	78	1	--	4	4	71	4

[1]Data are from Murphy and Shomura (1953a).

[2]Data are from Murphy and Shomura (1955).

[3]Data are from Shomura and Murphy (1955).

[4]Data are from Murphy and Shomura (1953b).

[5]Data are from Iversen and Yoshida (1956).

[6]Data are from Iversen and Yoshida (1957).

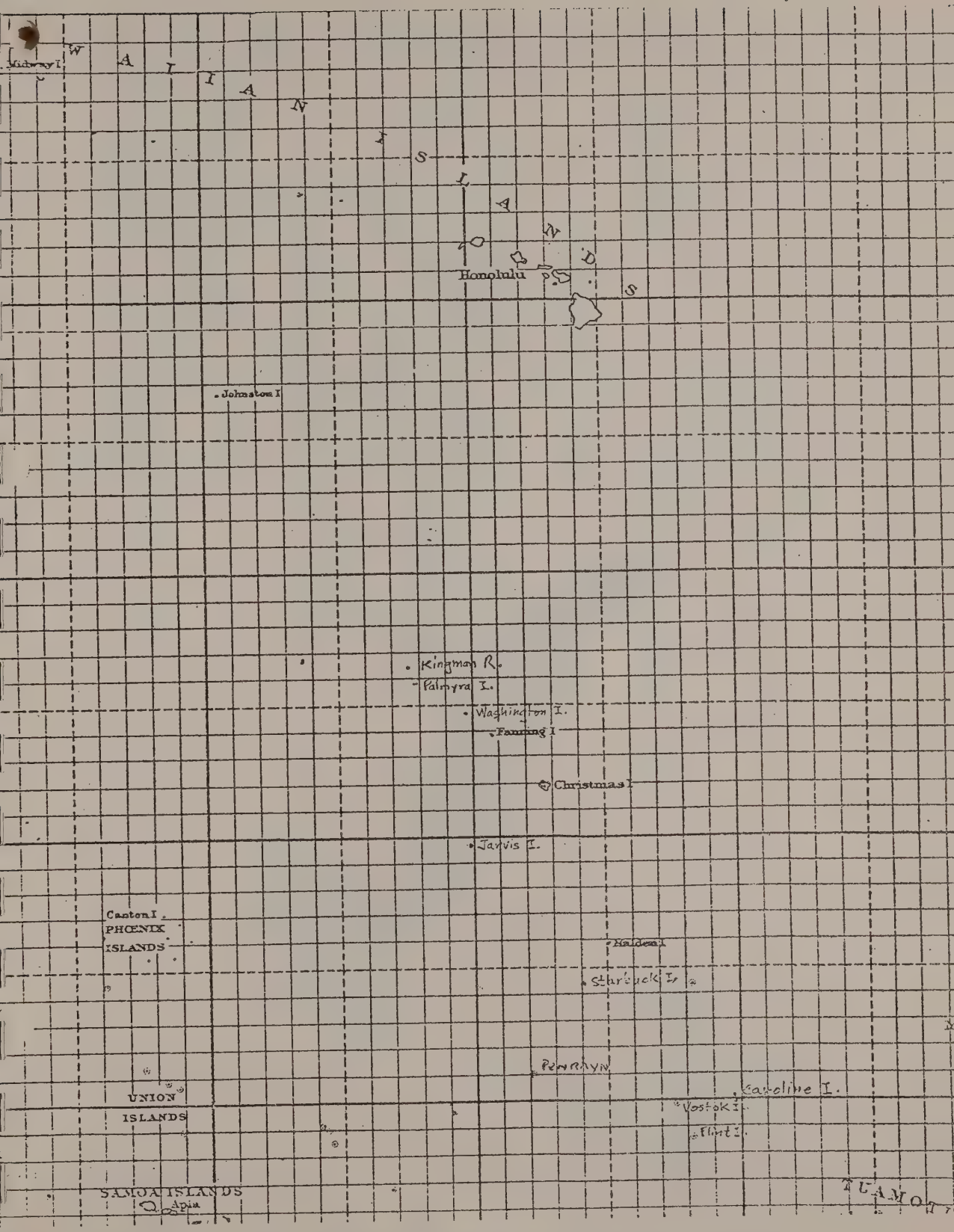


Figure 1.--The location of the Line Islands in the central equatorial Pacific Ocean.

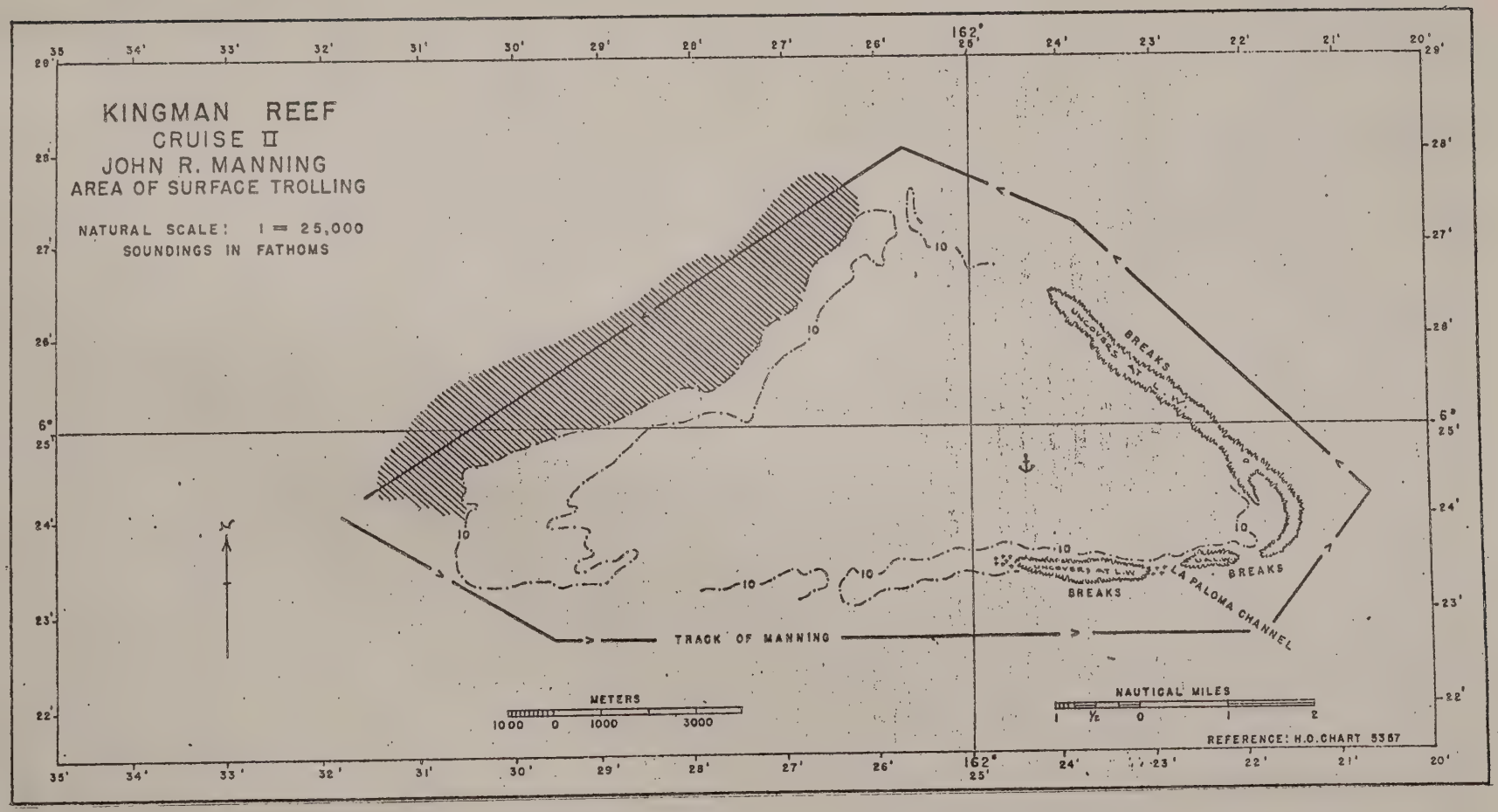


Figure 2.--Kingman Reef (from Bates 1950).

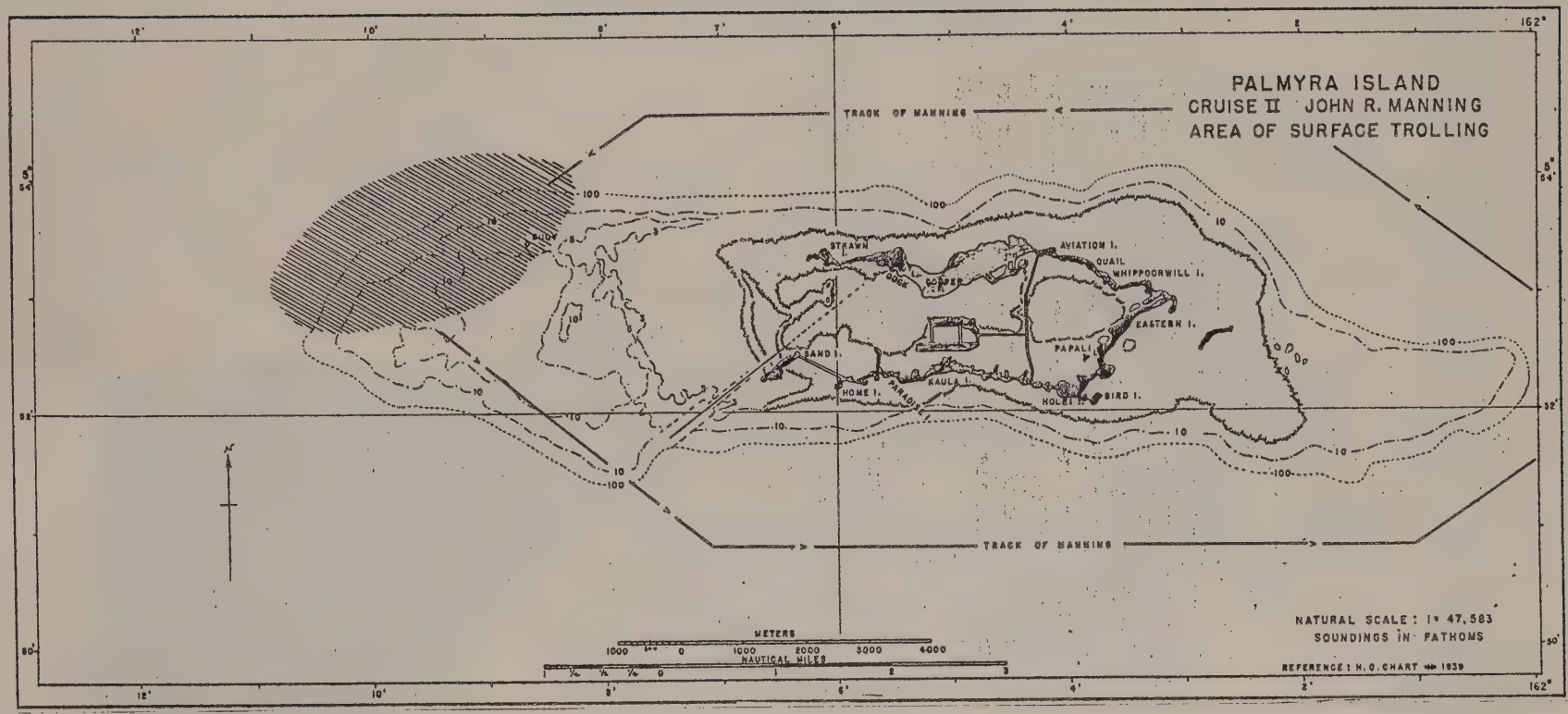


Figure 3.--Palmyra Island (from Bates 1950).

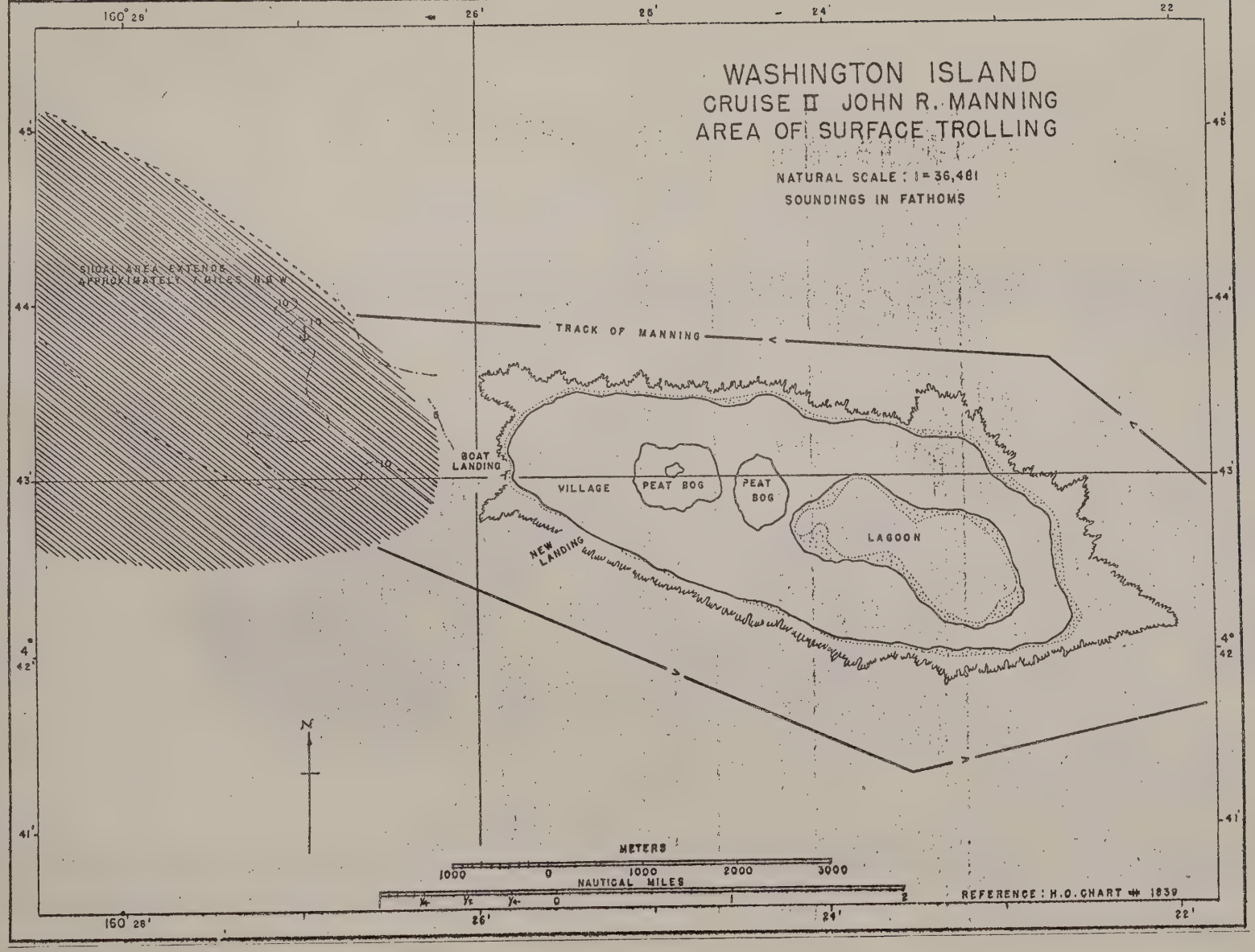


Figure 4.--Washington Island (from Bates 1950).

Figure 5.--Fanning Island (from Bates 1950).

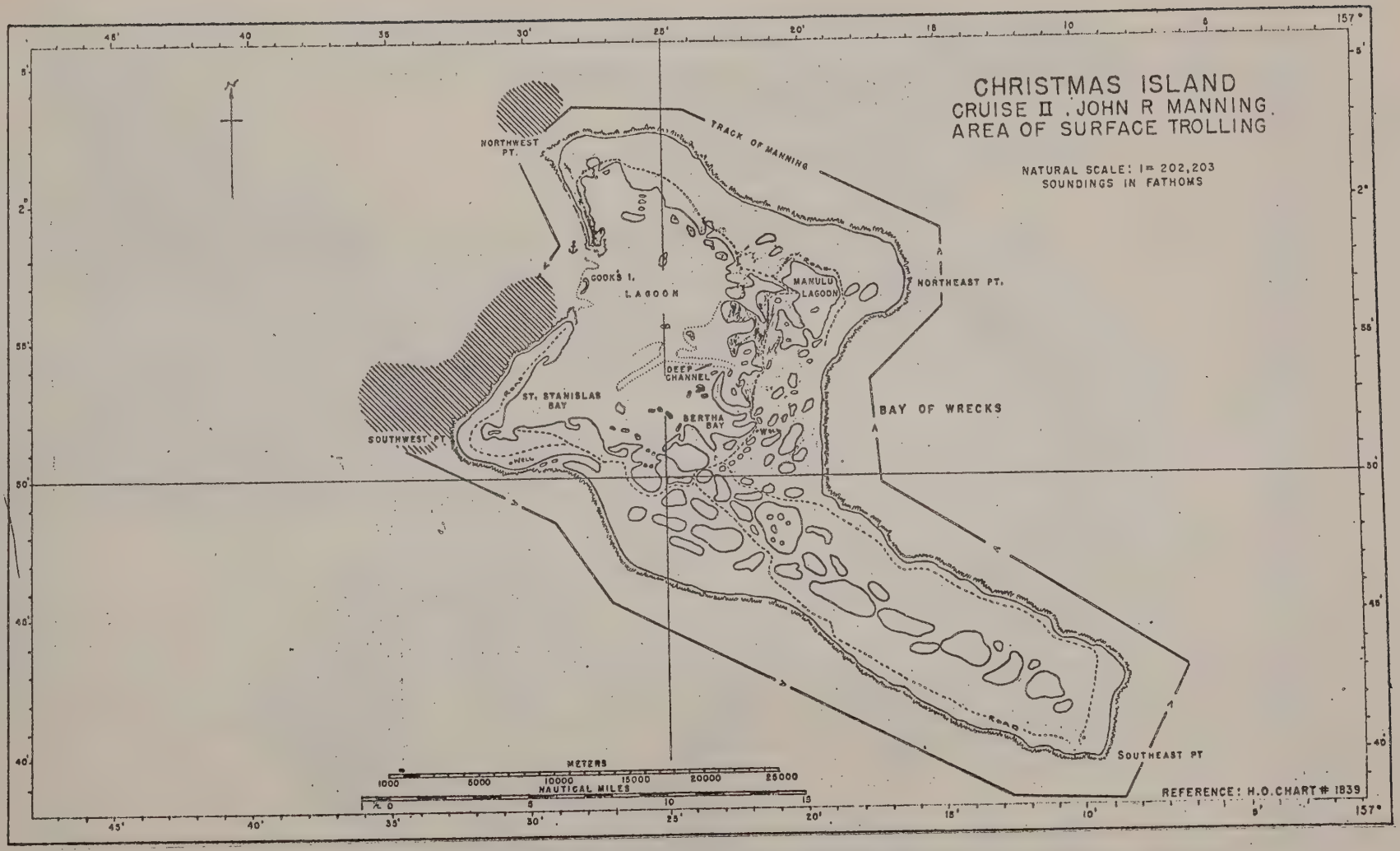


Figure 6.--Christmas Island (from Bates 1950).

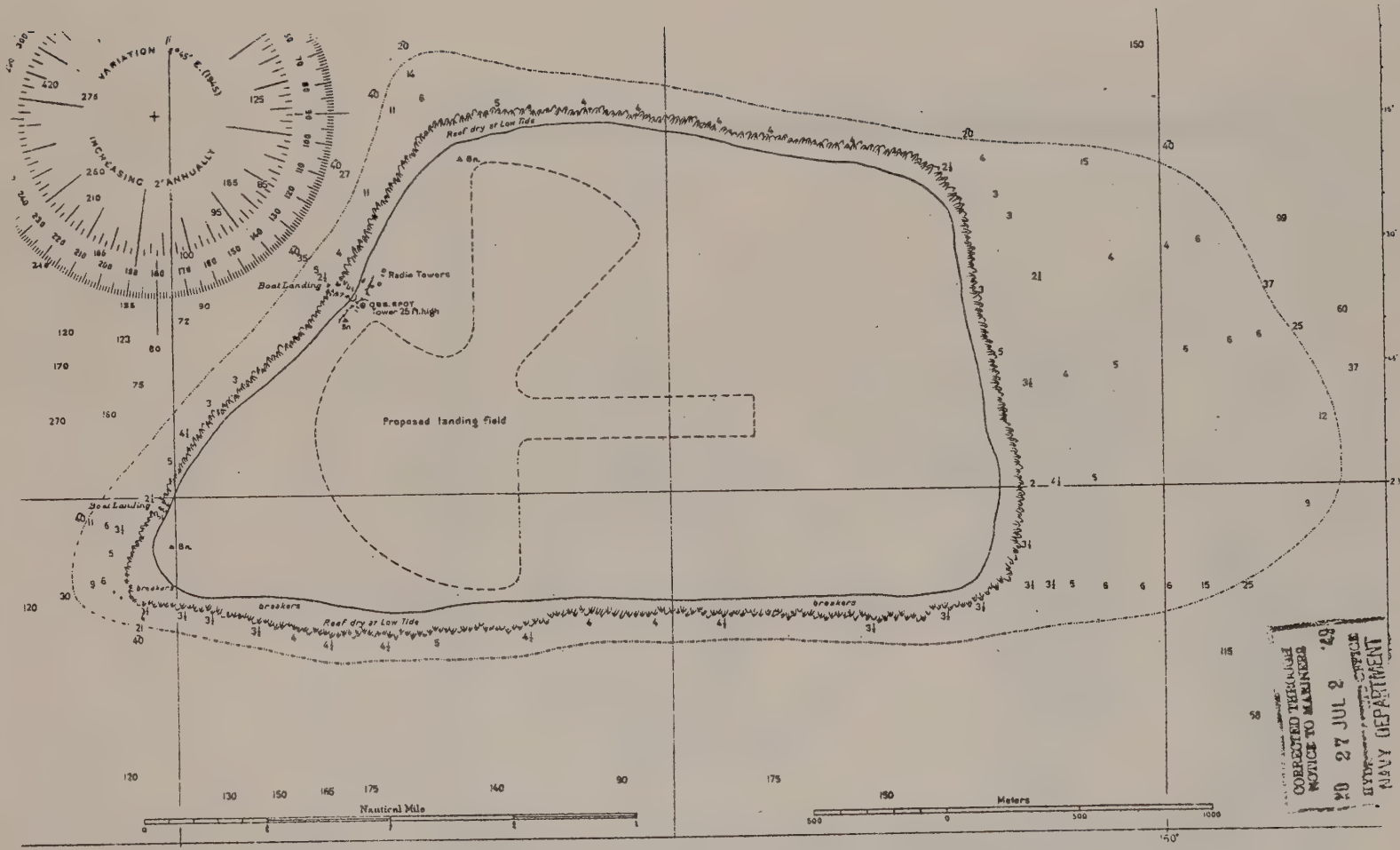


Figure 7.--Jarvis Island (from H. O. 1198, 11th ed., Sept. 1945).

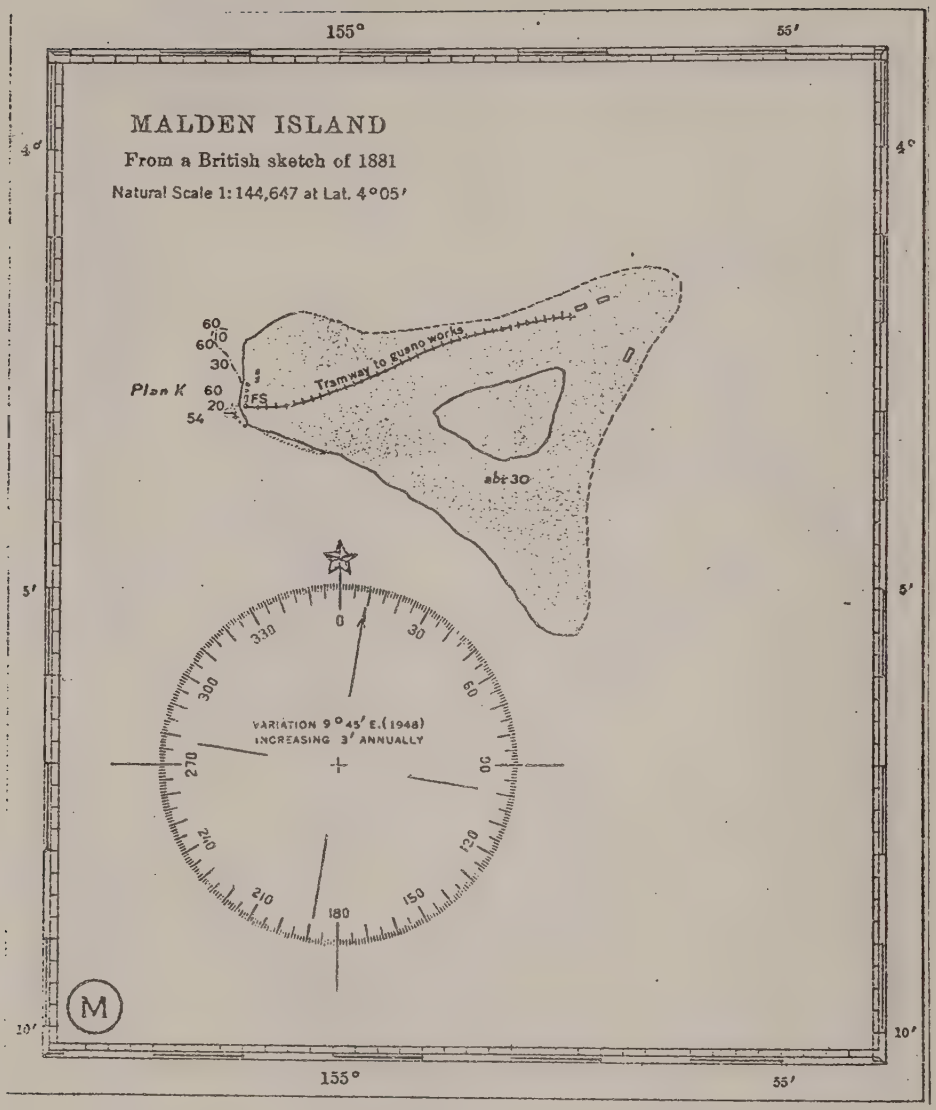


Figure 8.--Malden Island (from H. O. 1980, 9th ed., Mar. 1948).

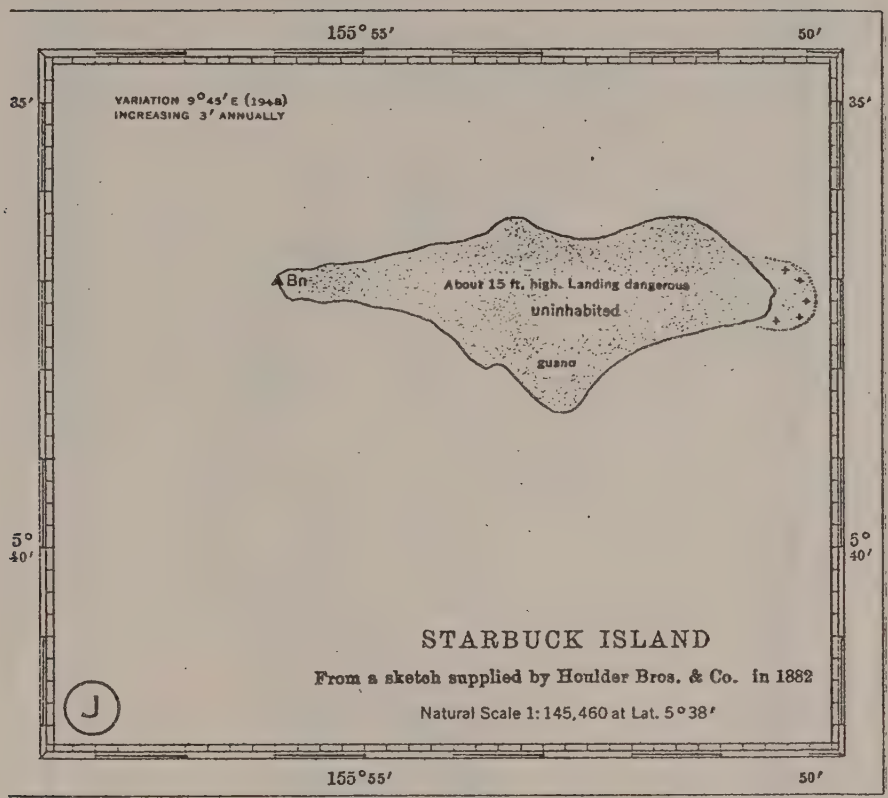


Figure 9.--Starbuck Island (from H. O. 1980, 9th ed., Mar. 1948).

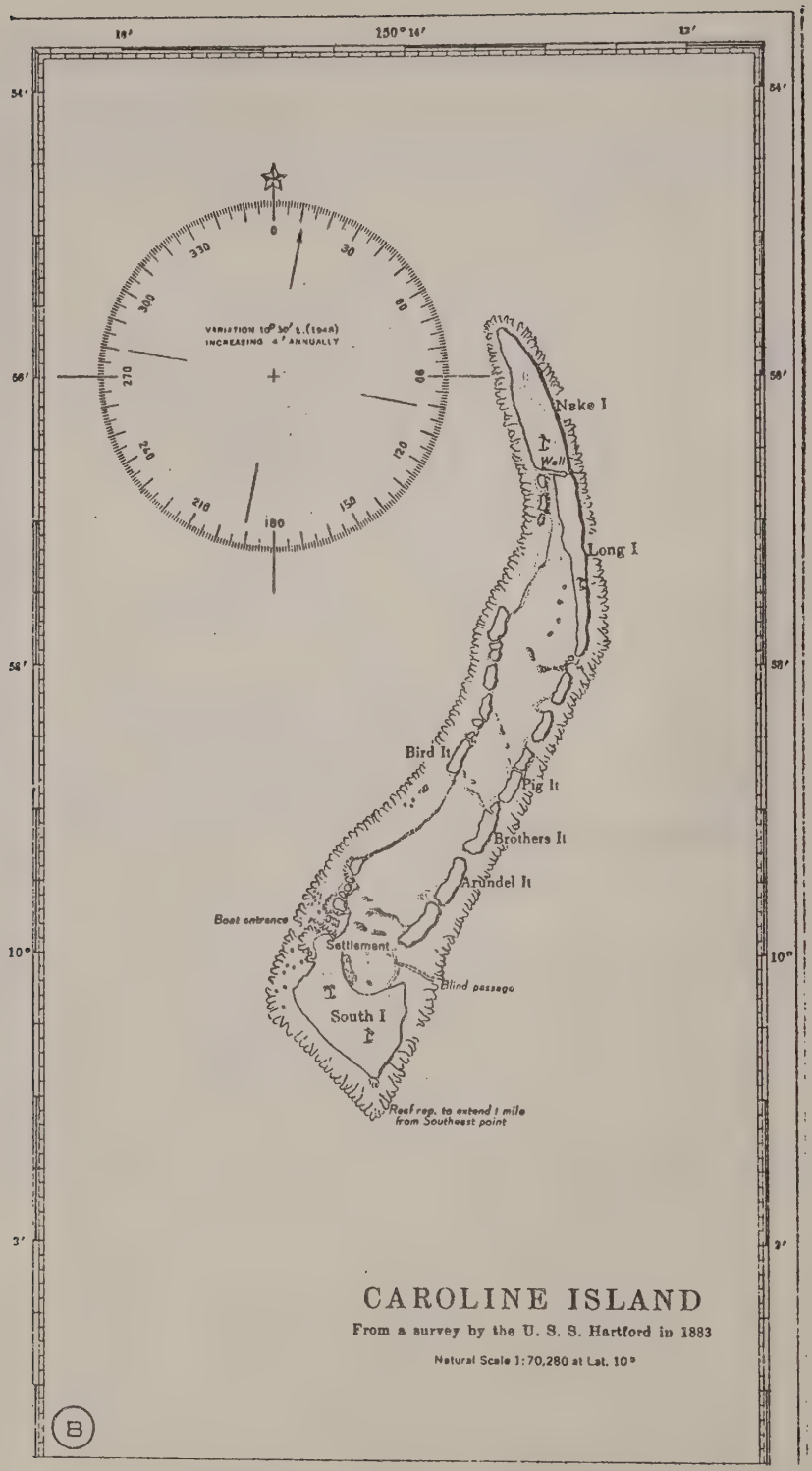


Figure 10.--Caroline Island (from H. O. 1980, 9th ed., Mar. 1948).

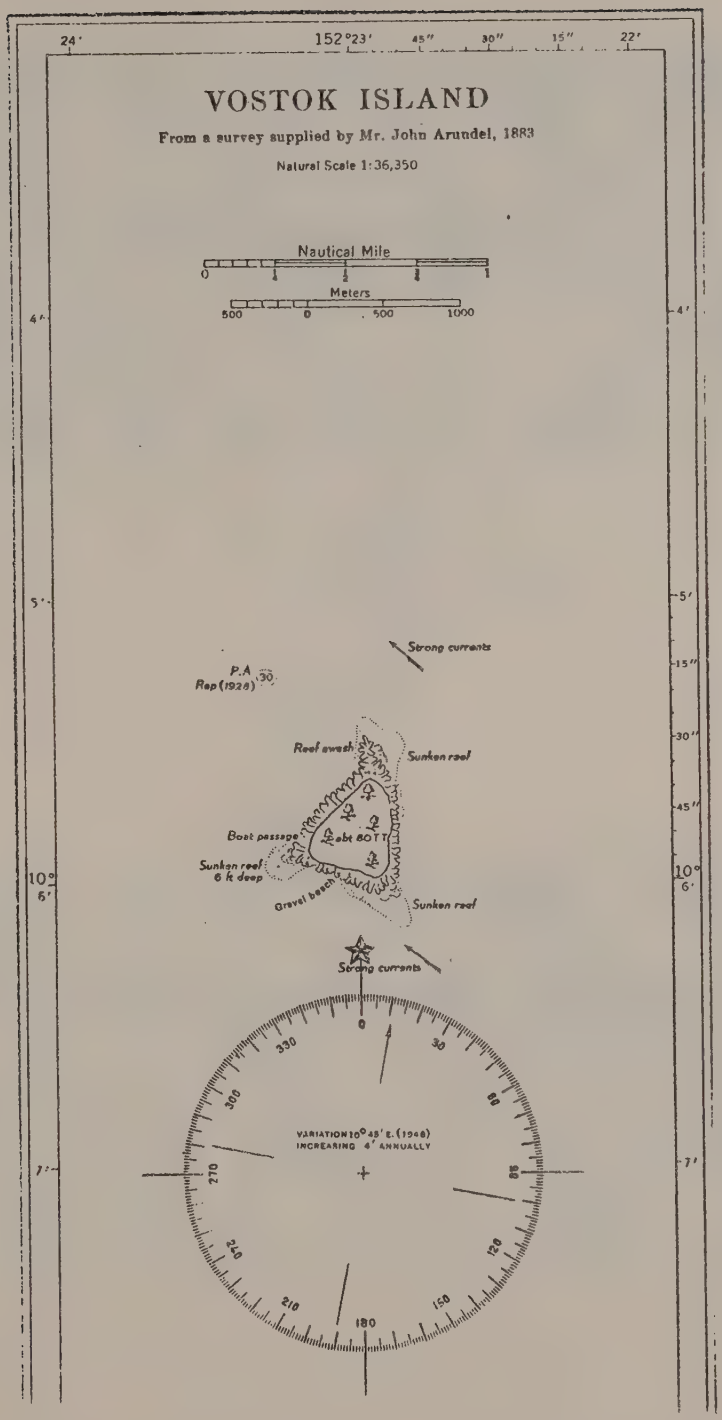


Figure 11.--Vostok Island (from H. O. 1980, 9th ed., Mar. 1948).

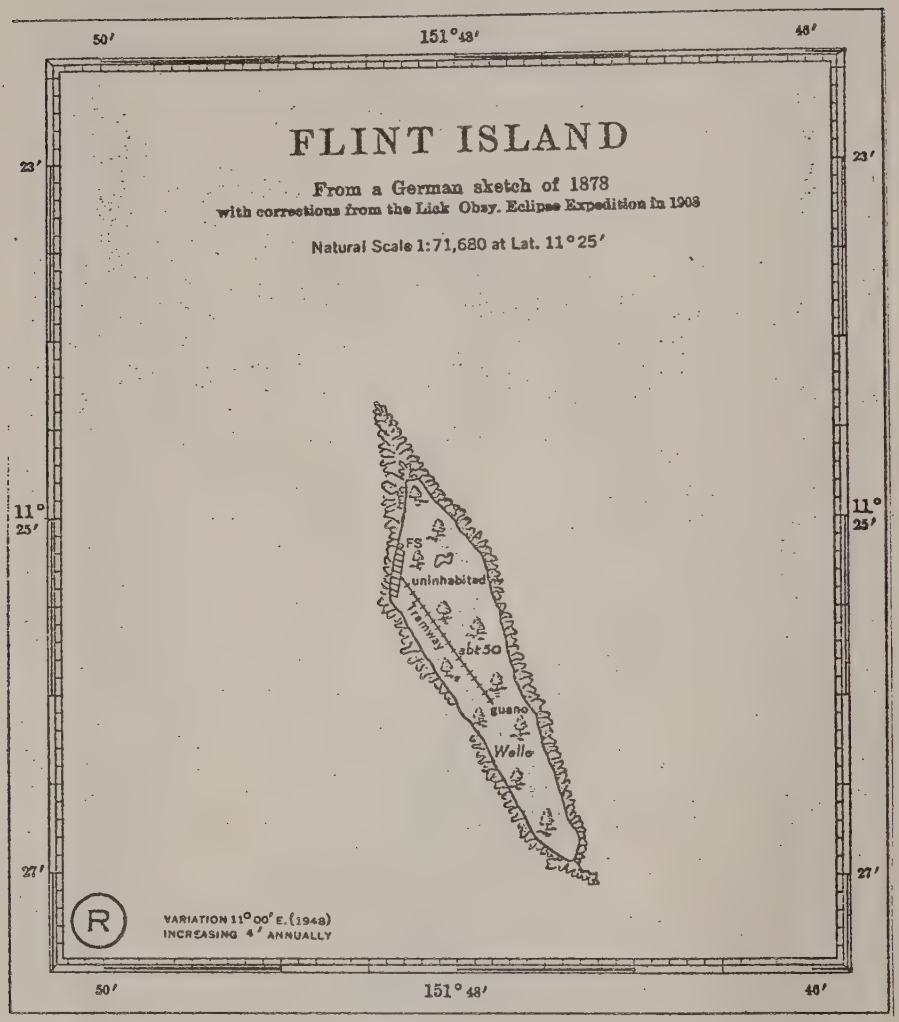


Figure 12.--Flint Island (from H. O. 1980, 9th ed., Mar. 1948).

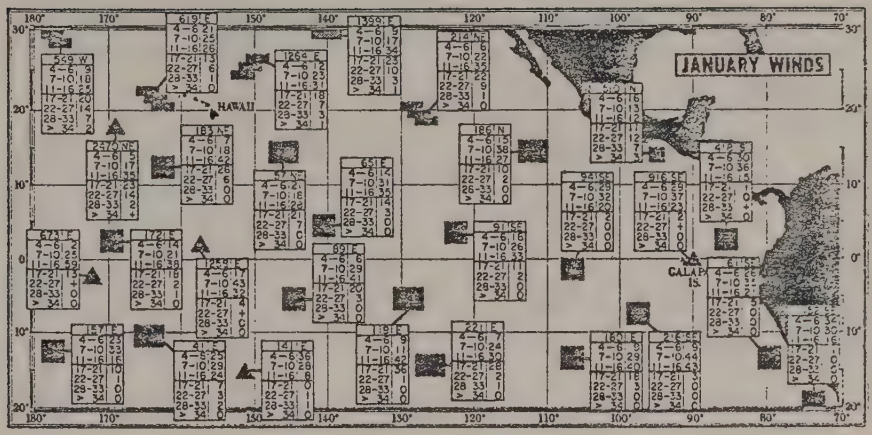


Figure 13.--January winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

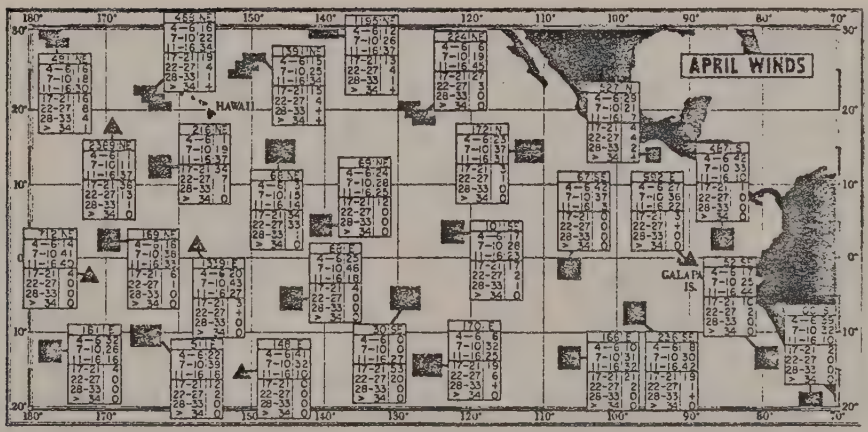


Figure 14.--April winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

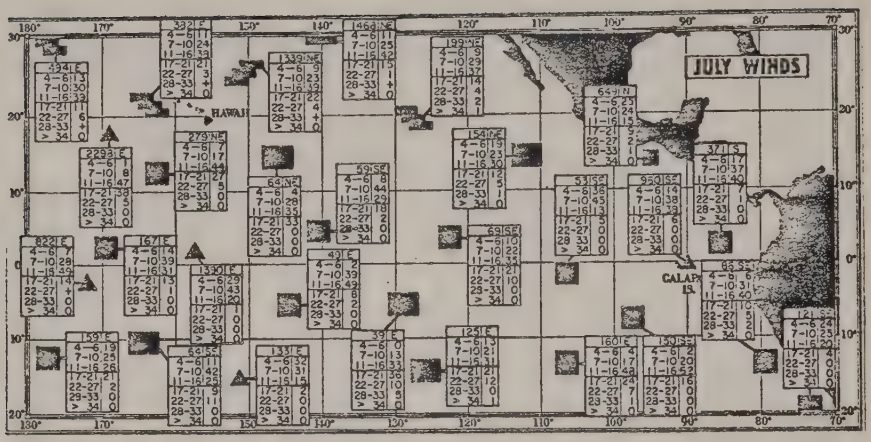


Figure 15.--July winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

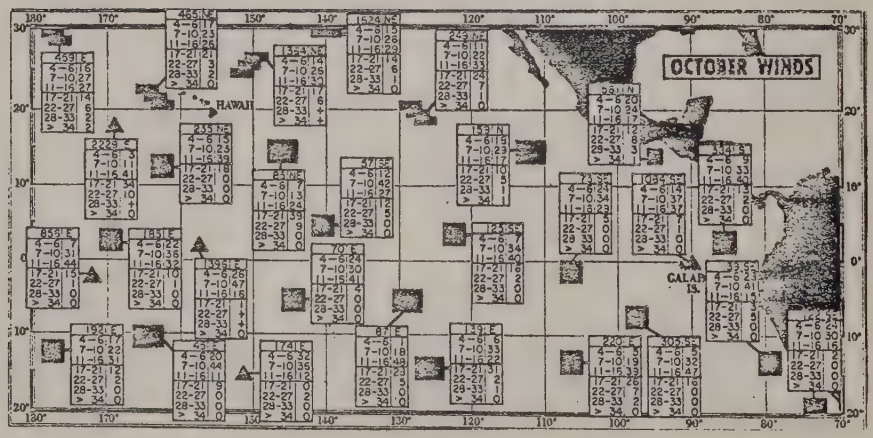


Figure 16.--October winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

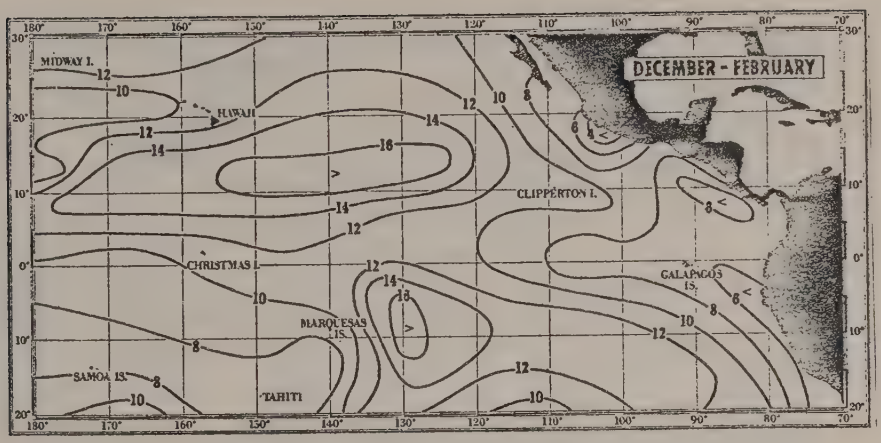


Figure 17.--Average wind velocities, December-February, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

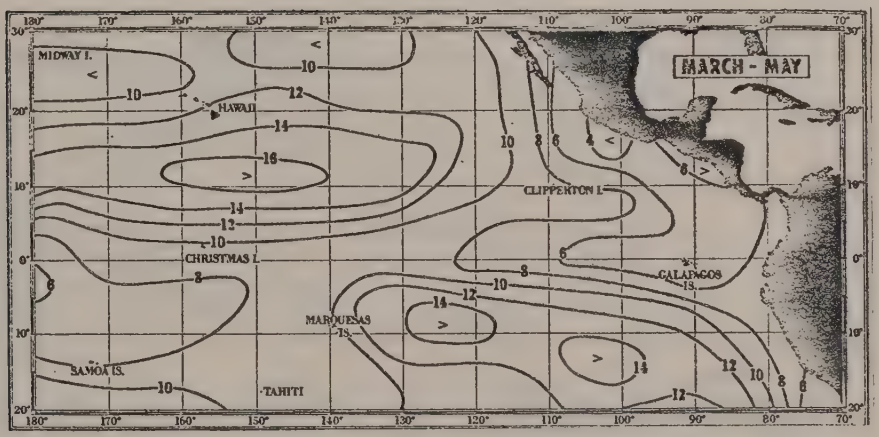


Figure 18.--Average wind velocities, March-May, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

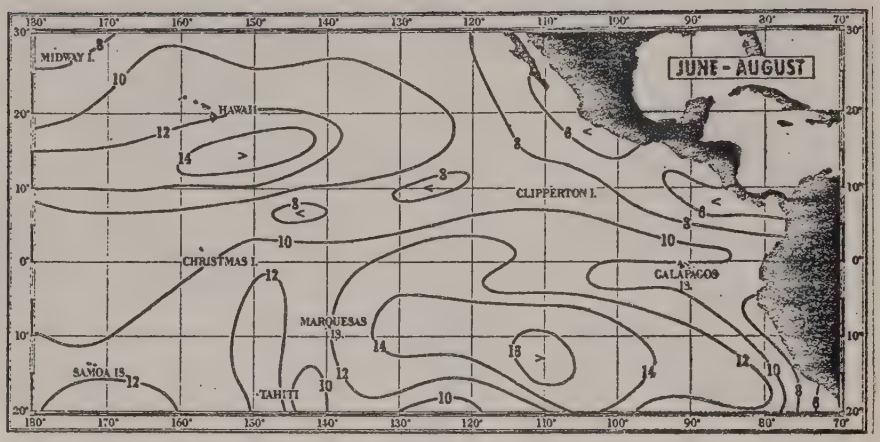


Figure 19.--Average wind velocities, June-August, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

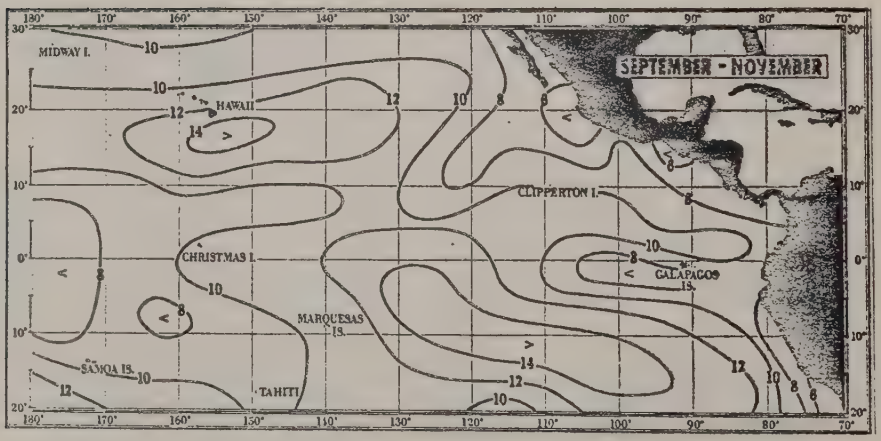


Figure 20.--Average wind velocities, September-November, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

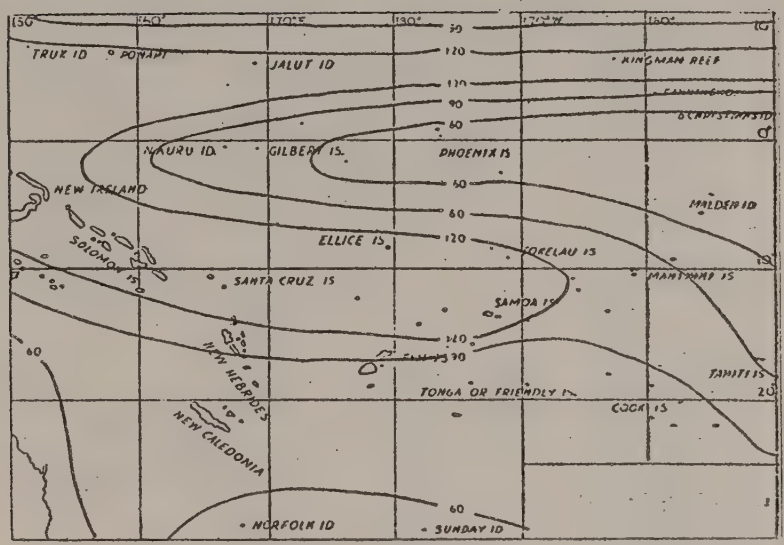


Figure 21.--Average annual rainfall in inches (from Seelye 1950).

Figure 22.--Location of wet and dry islands in the central equatorial Pacific Ocean (from Bryan 1941).

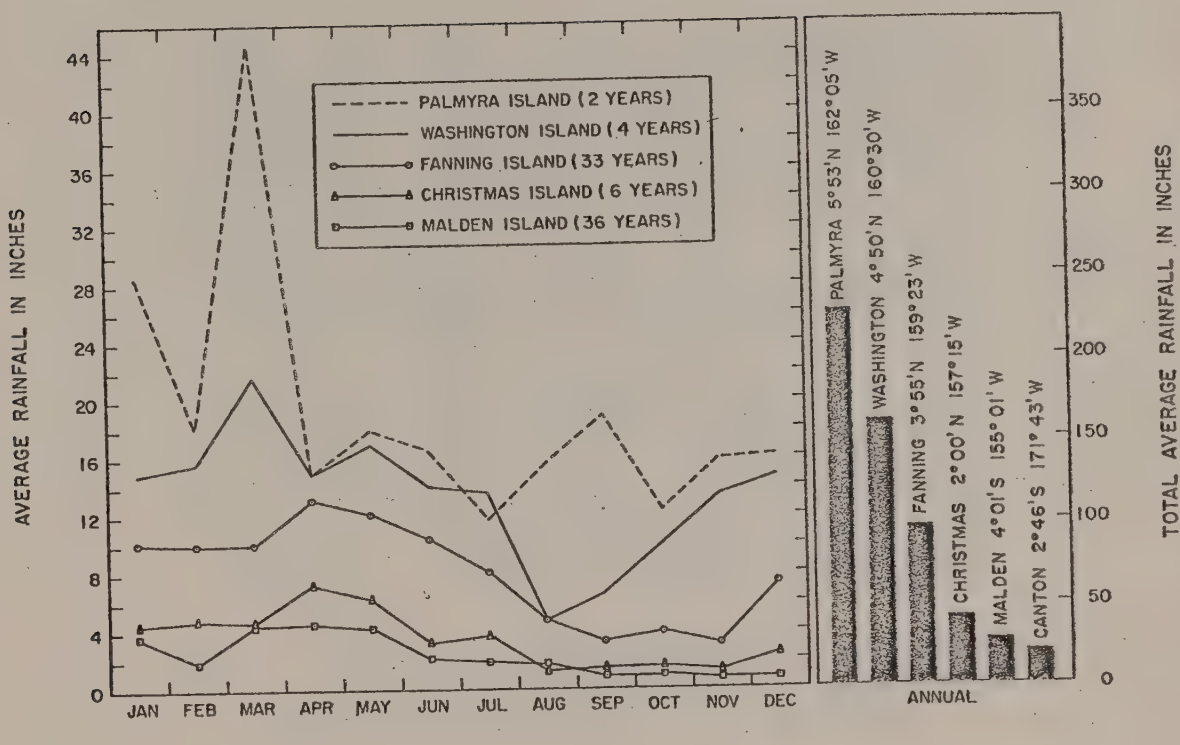


Figure 23.--Average monthly and annual rainfall for Palmyra, Washington, Fanning, Christmas, Malden, and Canton Islands (from Austin 1954b).

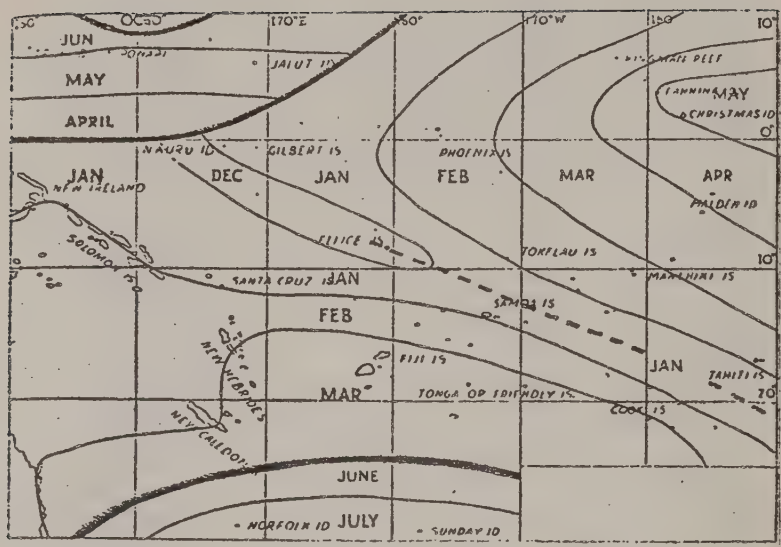


Figure 24.--Month of highest average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

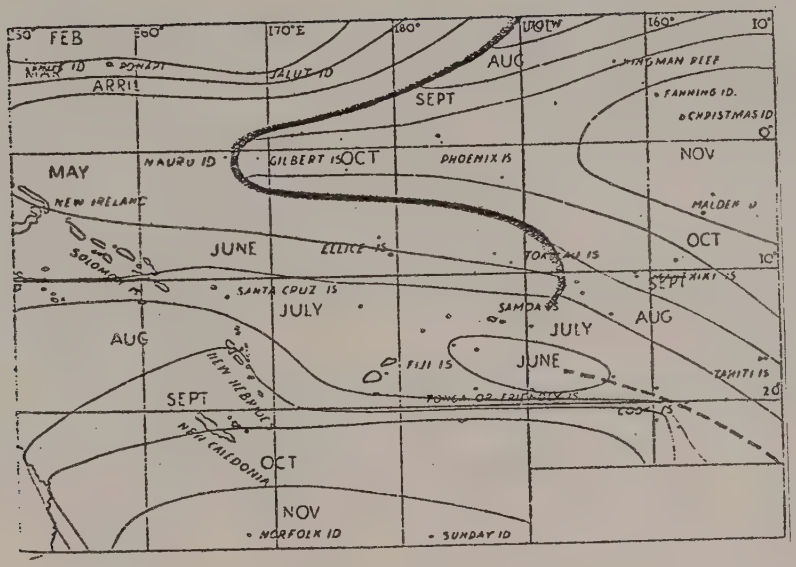


Figure 25.--Month of least average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

(+ = annual means)

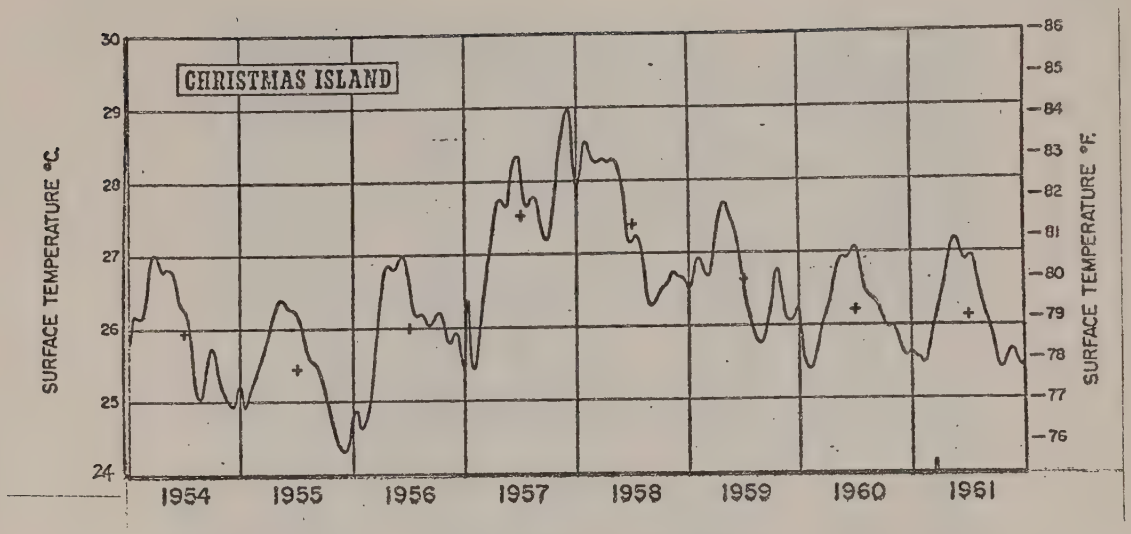


Figure 26.--Bi-monthly averages of sea-surface temperatures at Christmas Island (Barkley 1962, see footnote 3).

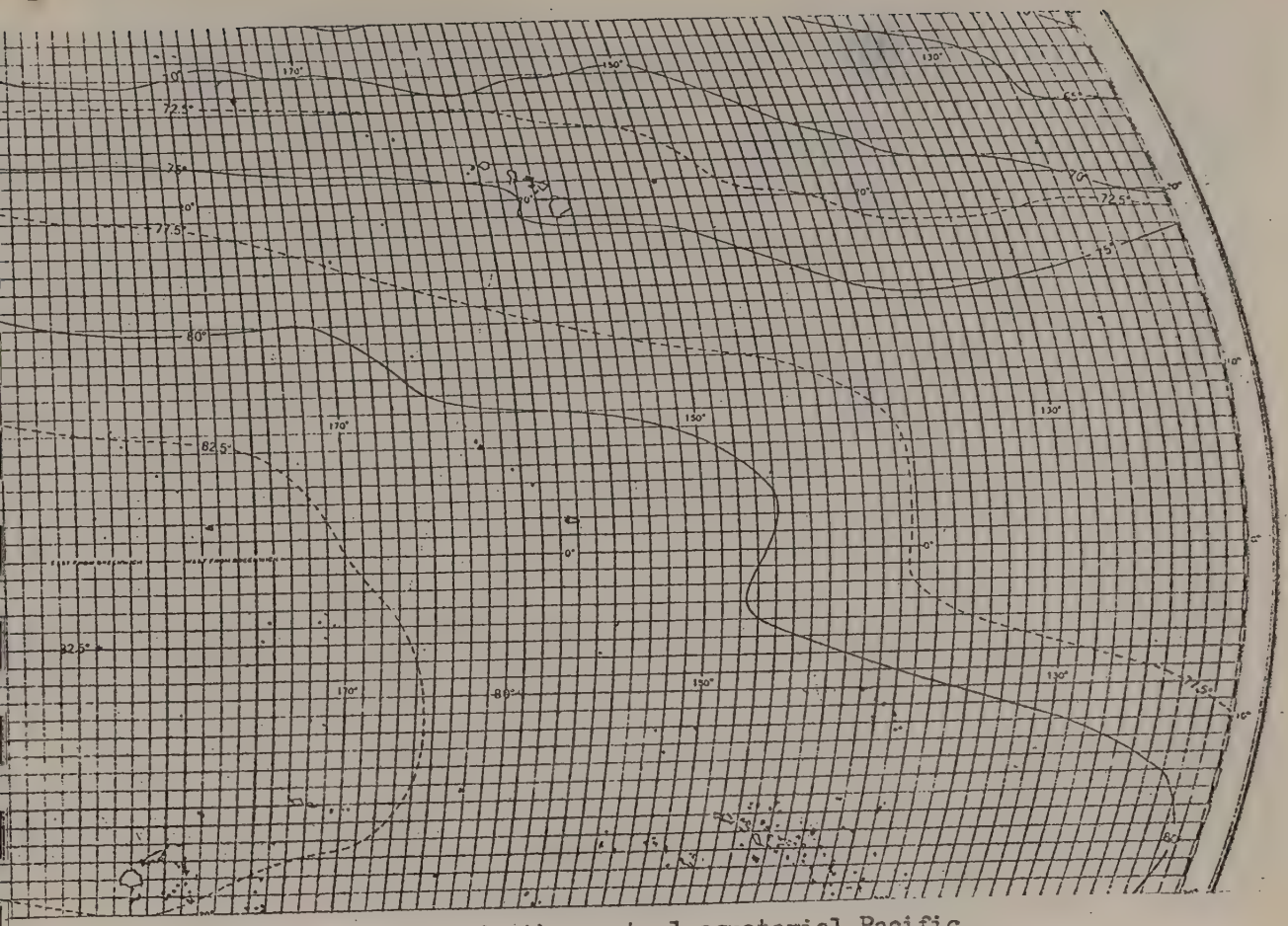


Figure 27a.--Surface temperature in the central equatorial Pacific Ocean in January (from U. S. Navy Hydrographic Office 1944).

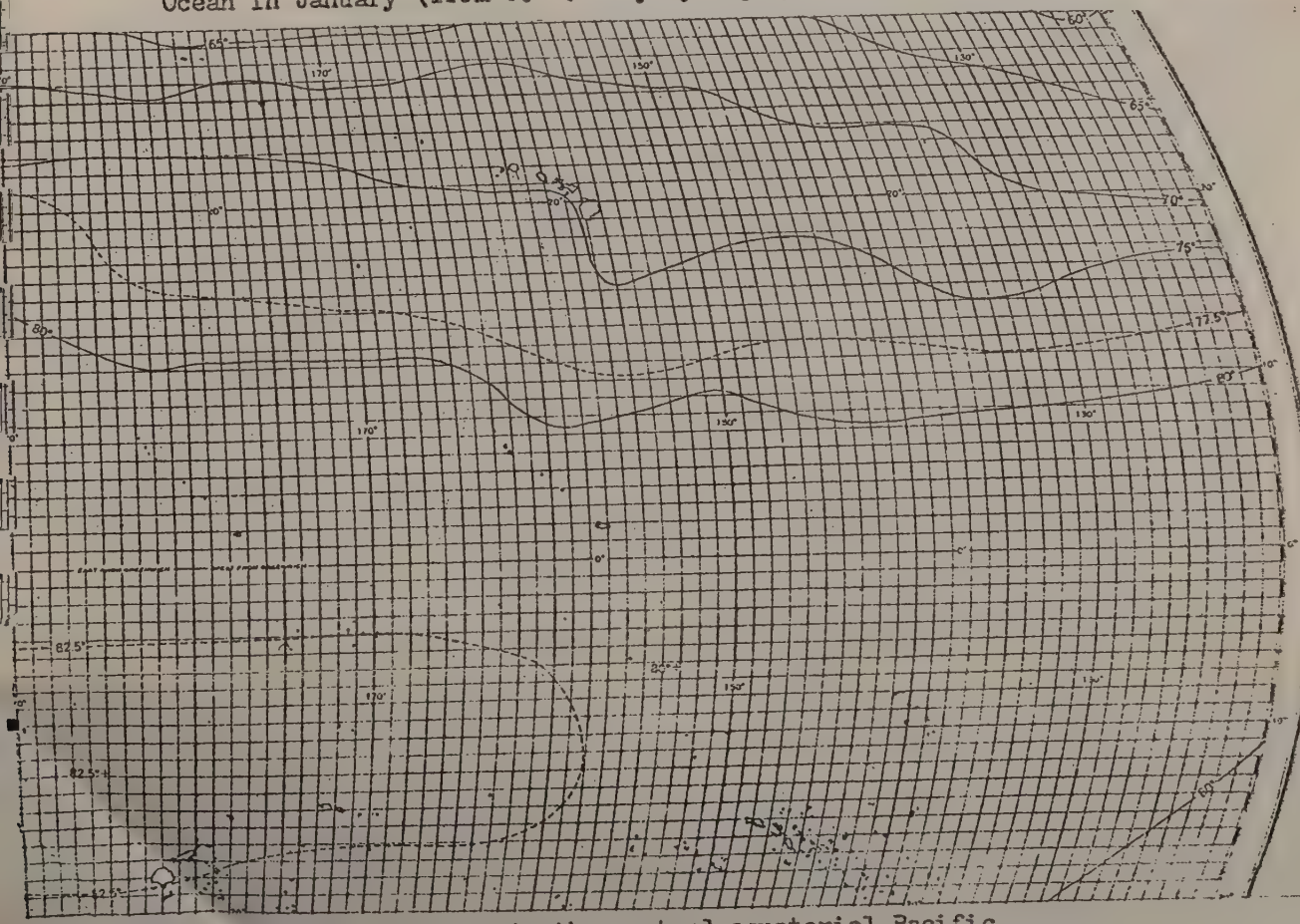


Figure 27b.--Surface temperature in the central equatorial Pacific Ocean in February (from U. S. Navy Hydrographic Office 1944).

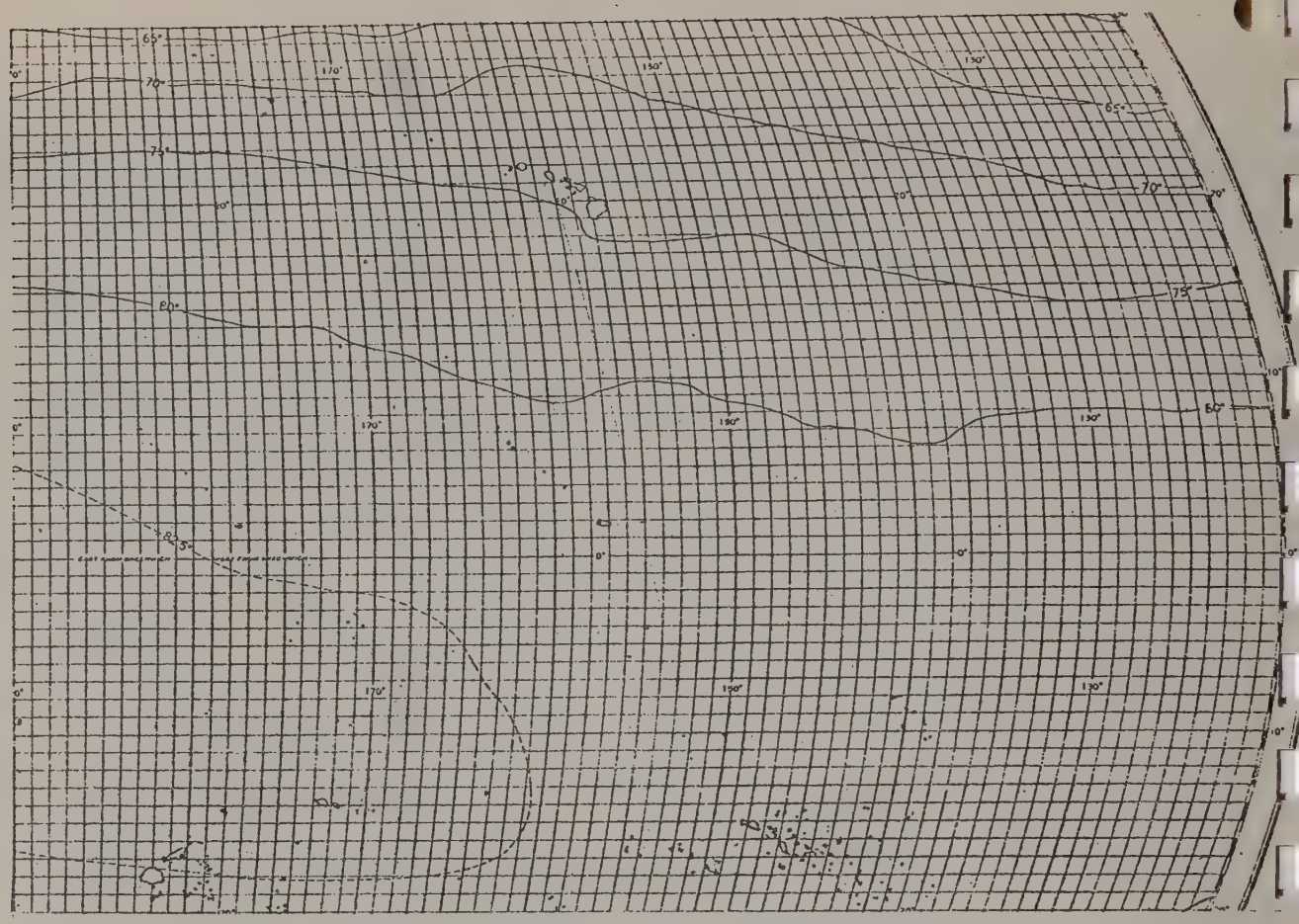


Figure 27c.--Surface temperature in the central equatorial Pacific Ocean in March (from U. S. Navy Hydrographic Office 1944).

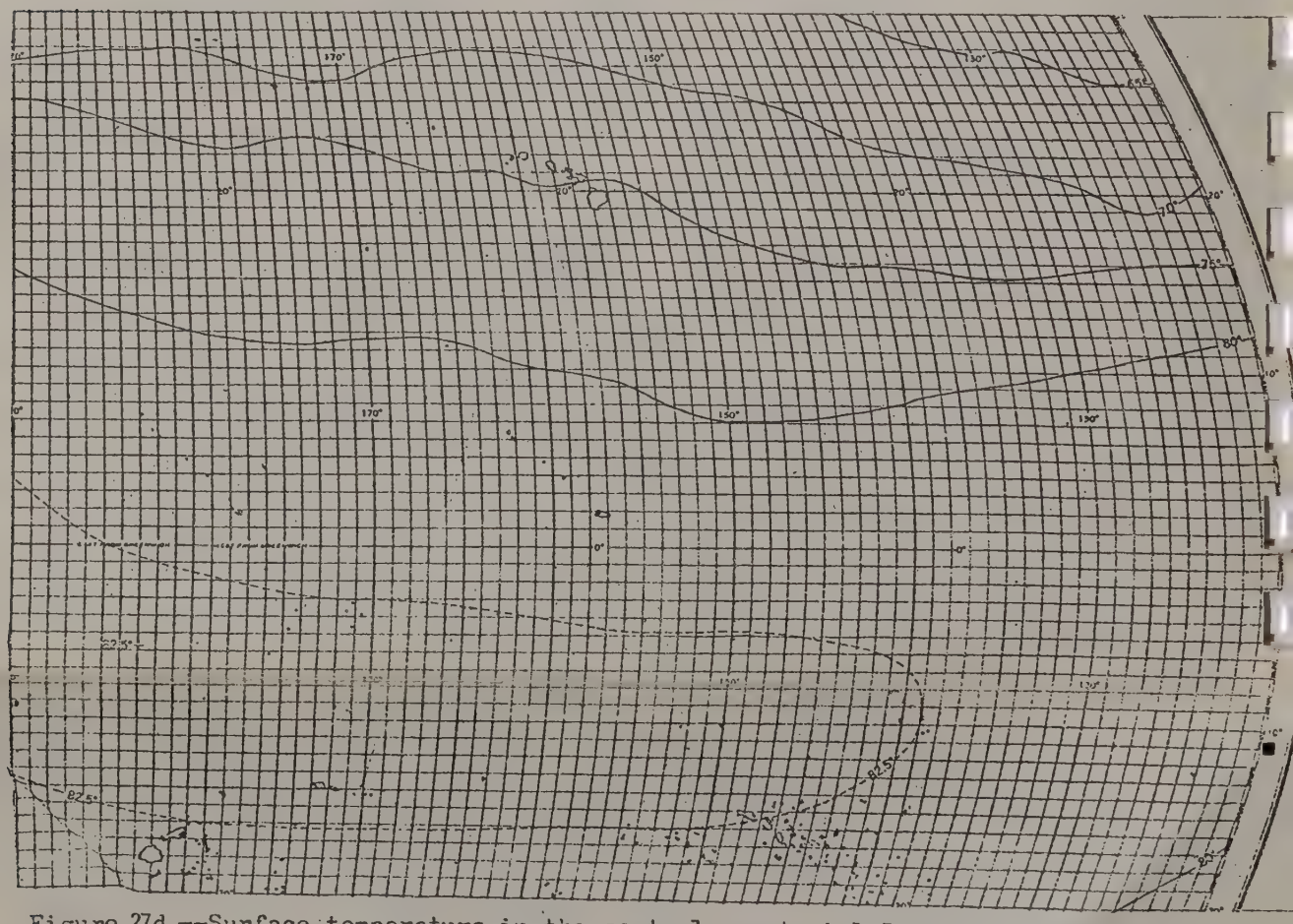
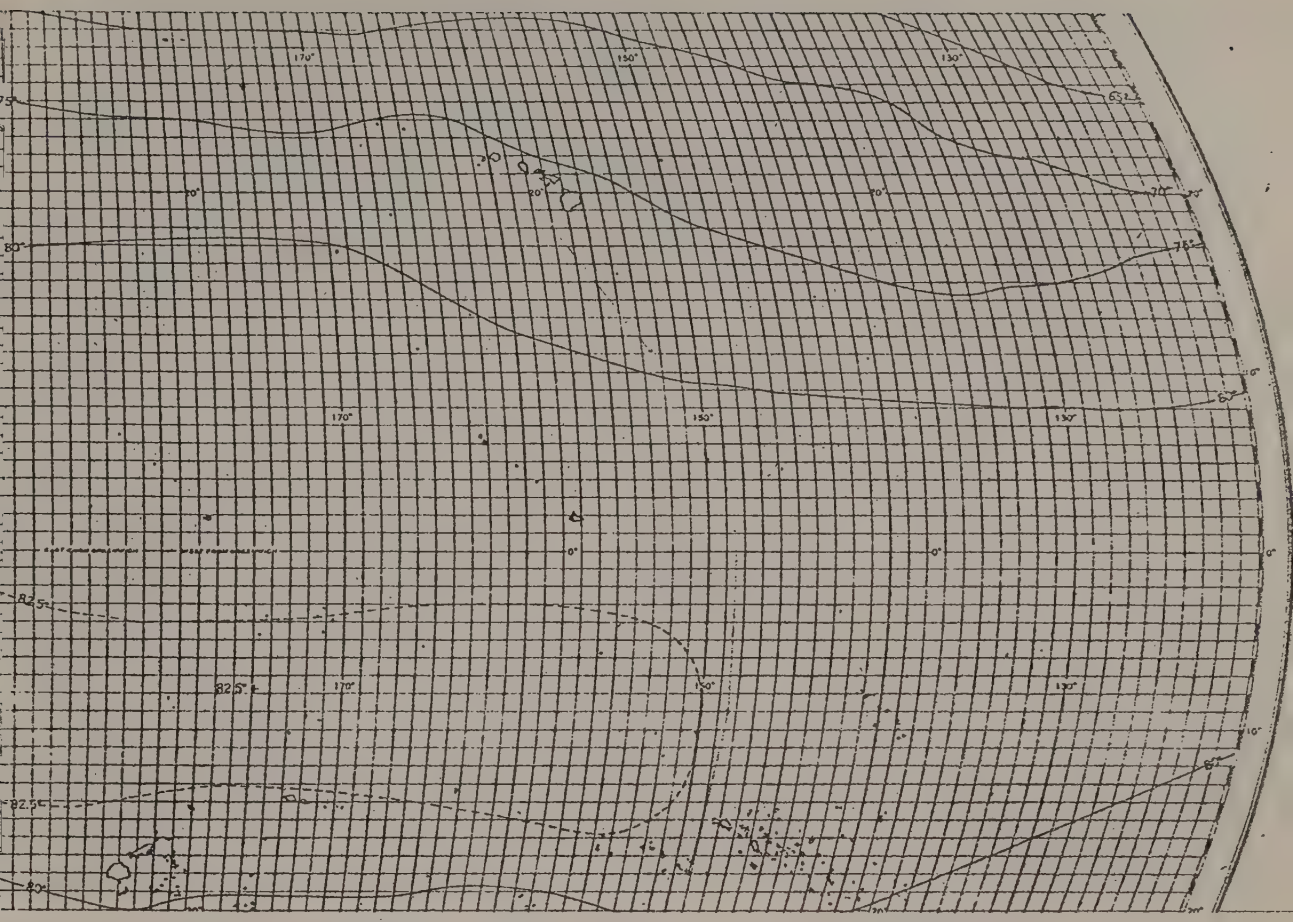


Figure 27d.--Surface temperature in the central equatorial Pacific Ocean in April (from U. S. Navy Hydrographic Office 1944).



igure 27e.--Surface temperature in the central equatorial Pacific Ocean in May (from U. S. Navy Hydrographic Office 1944).

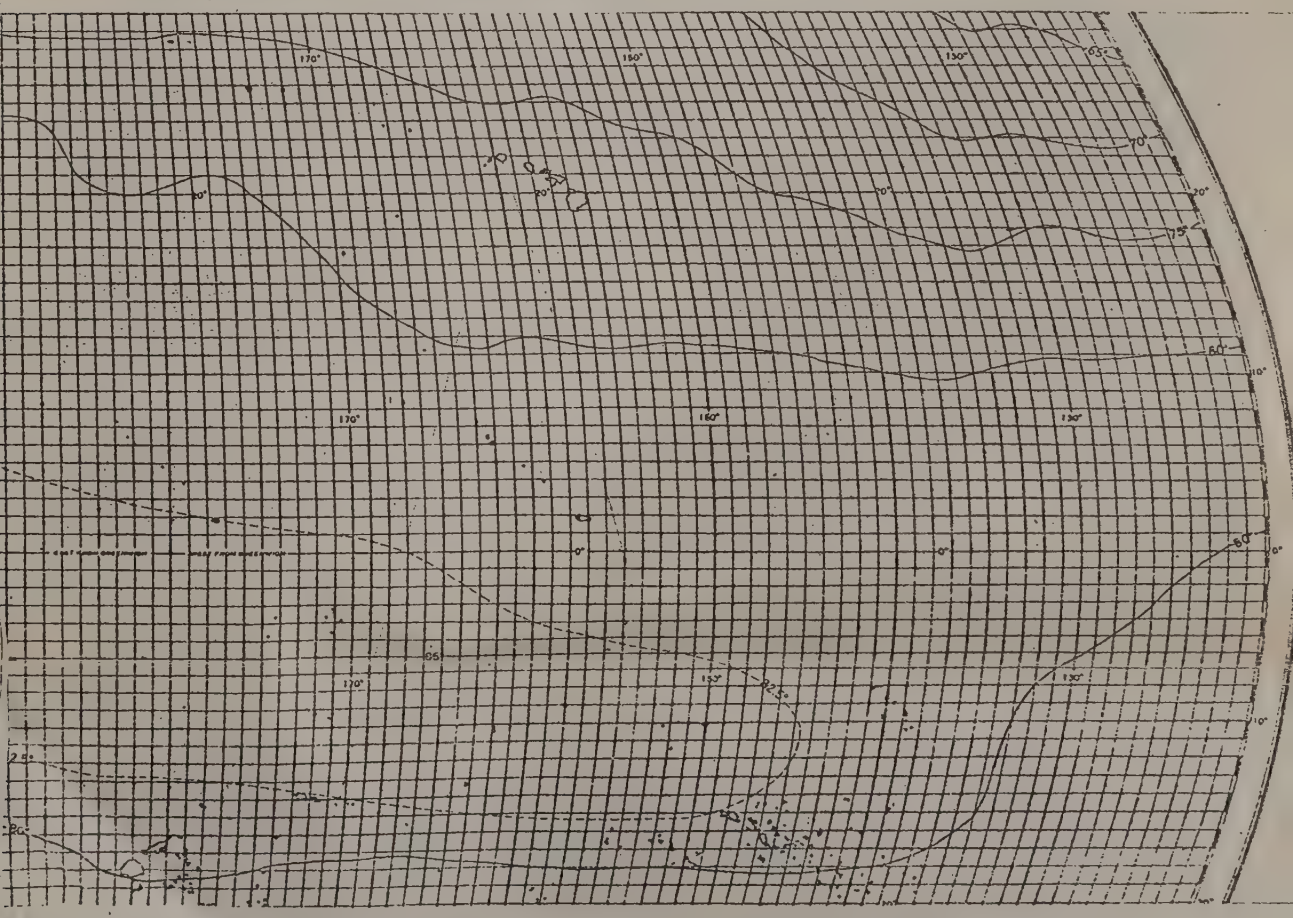


Figure 27f.--Surface temperature in the central equatorial Pacific Ocean in June (from U. S. Navy Hydrographic Office 1944).

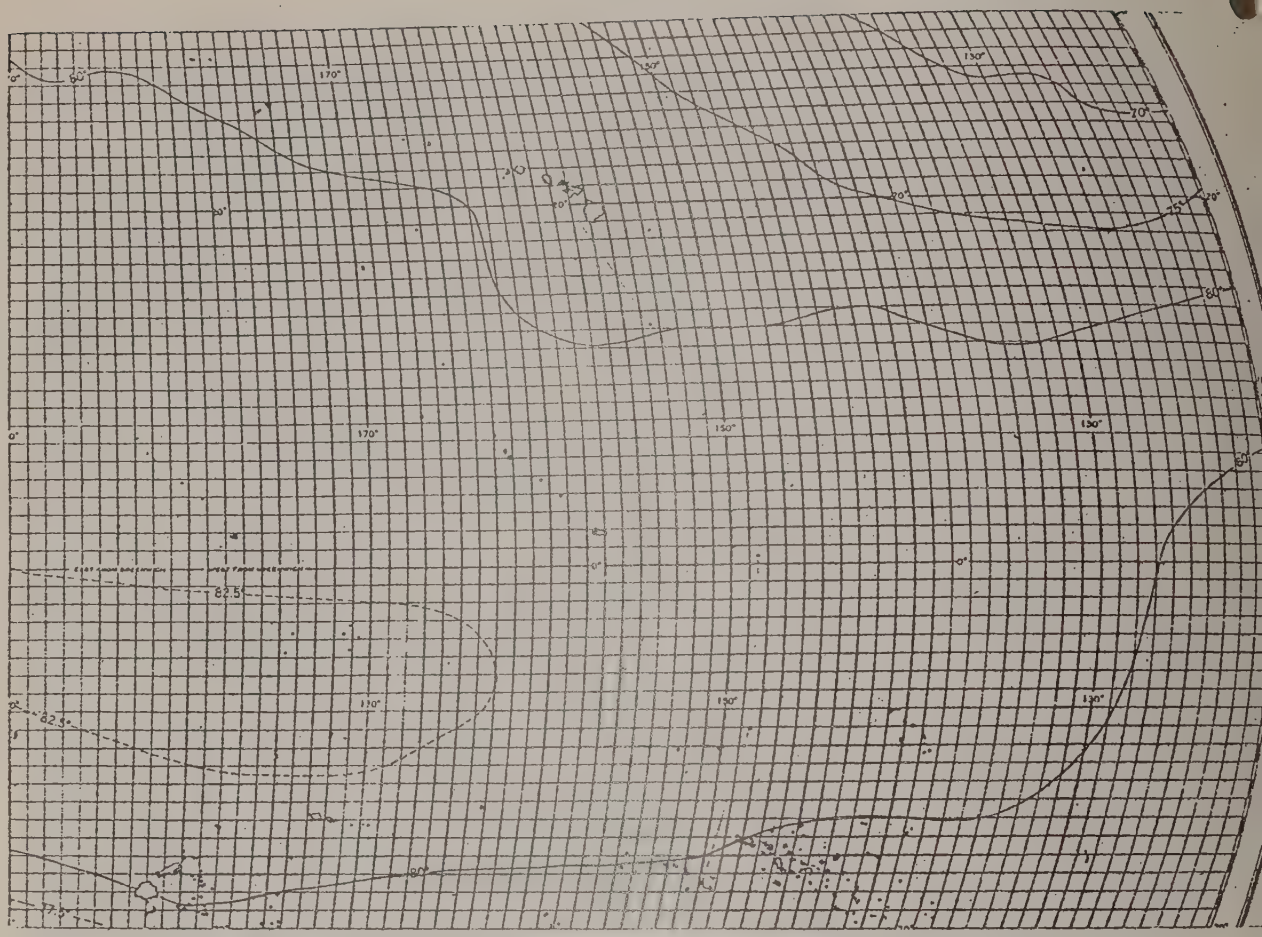


Figure 27g.--Surface temperature in the central equatorial Pacific Ocean in July (from U. S. Navy Hydrographic Office 1944).

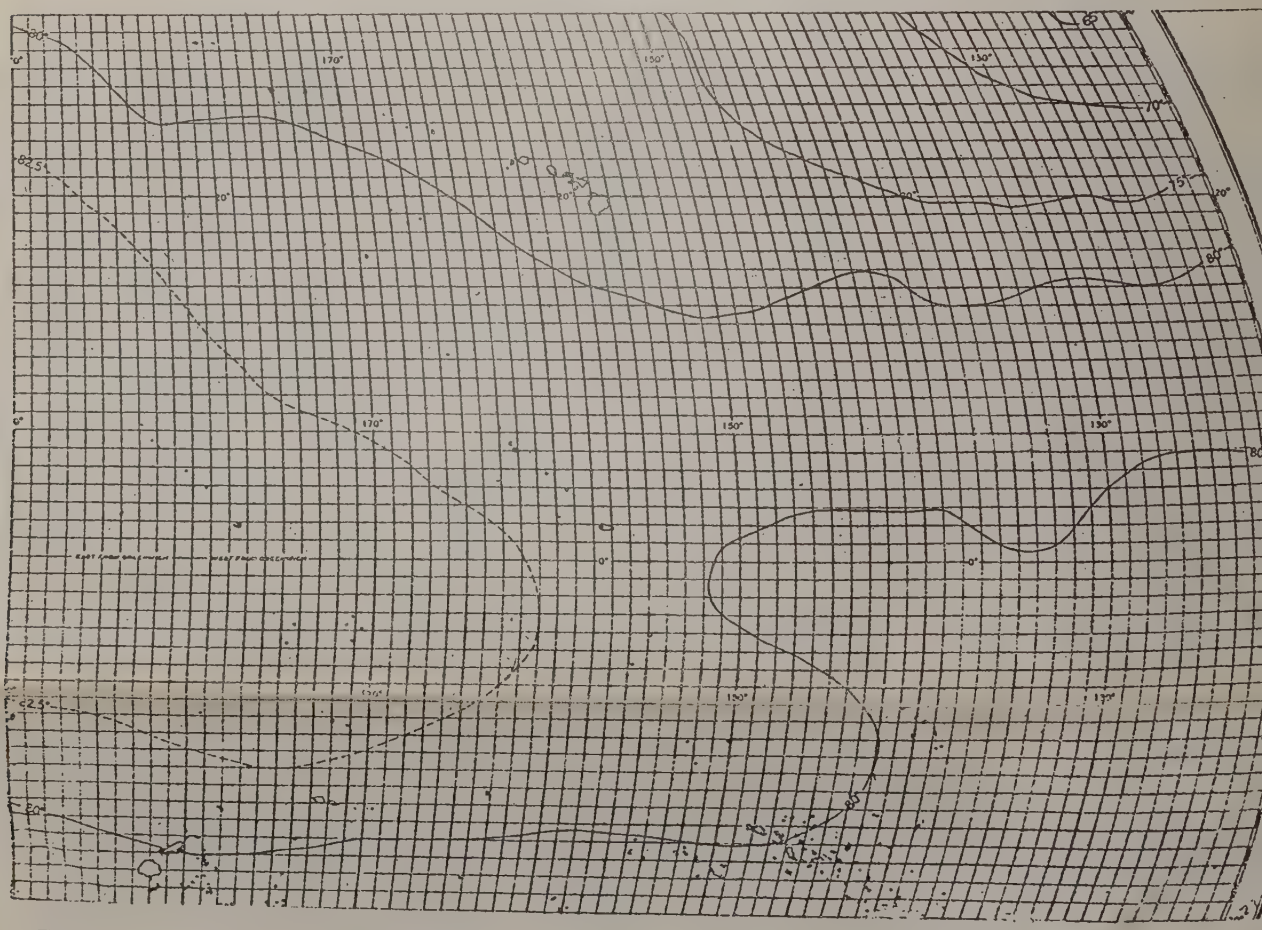


Figure 27h.--Surface temperature in the central equatorial Pacific Ocean in August (from U. S. Navy Hydrographic Office 1944).

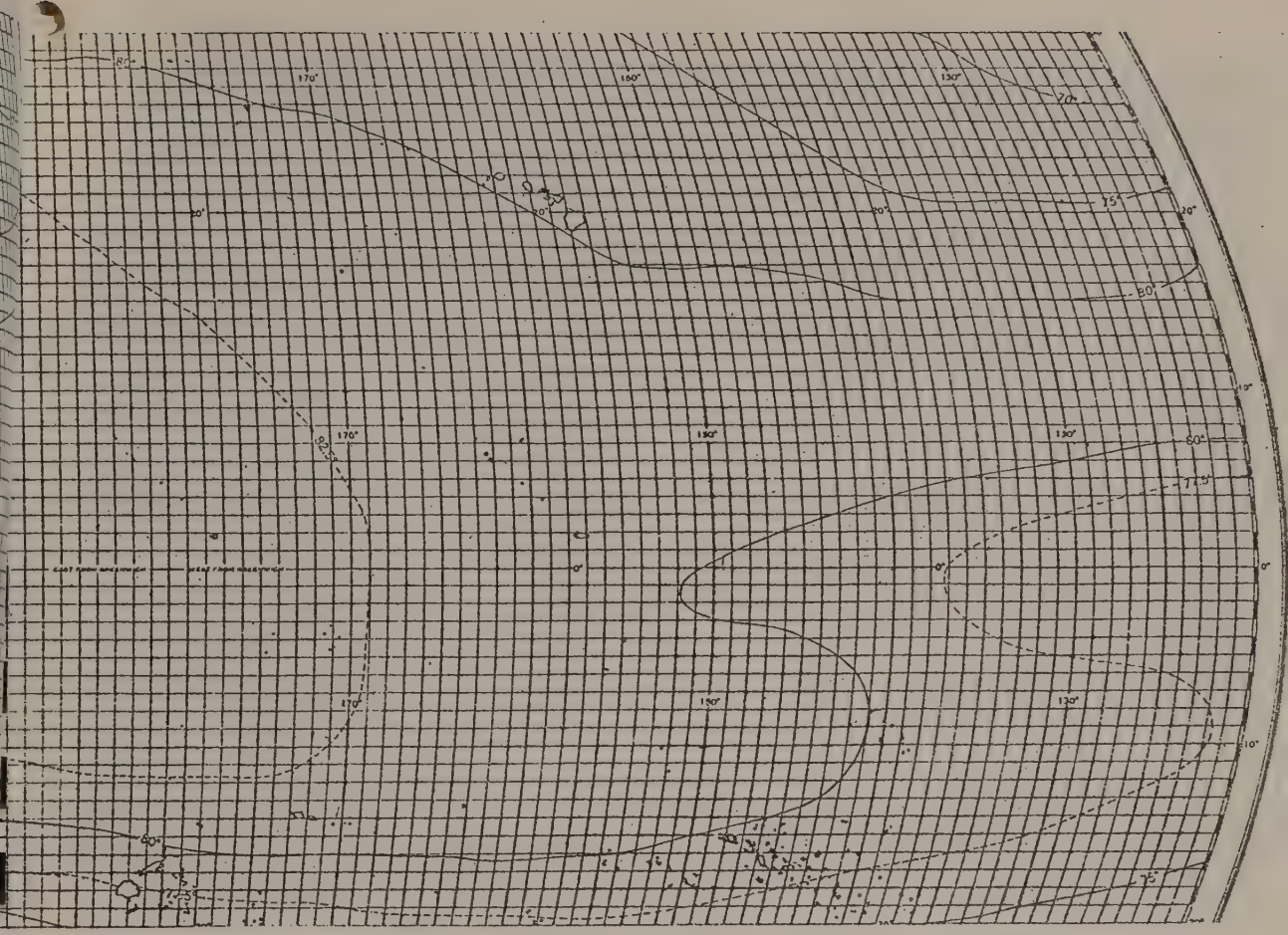


Figure 27i.—Surface temperature in the central equatorial Pacific Ocean in September (from U. S. Navy Hydrographic Office 1944).

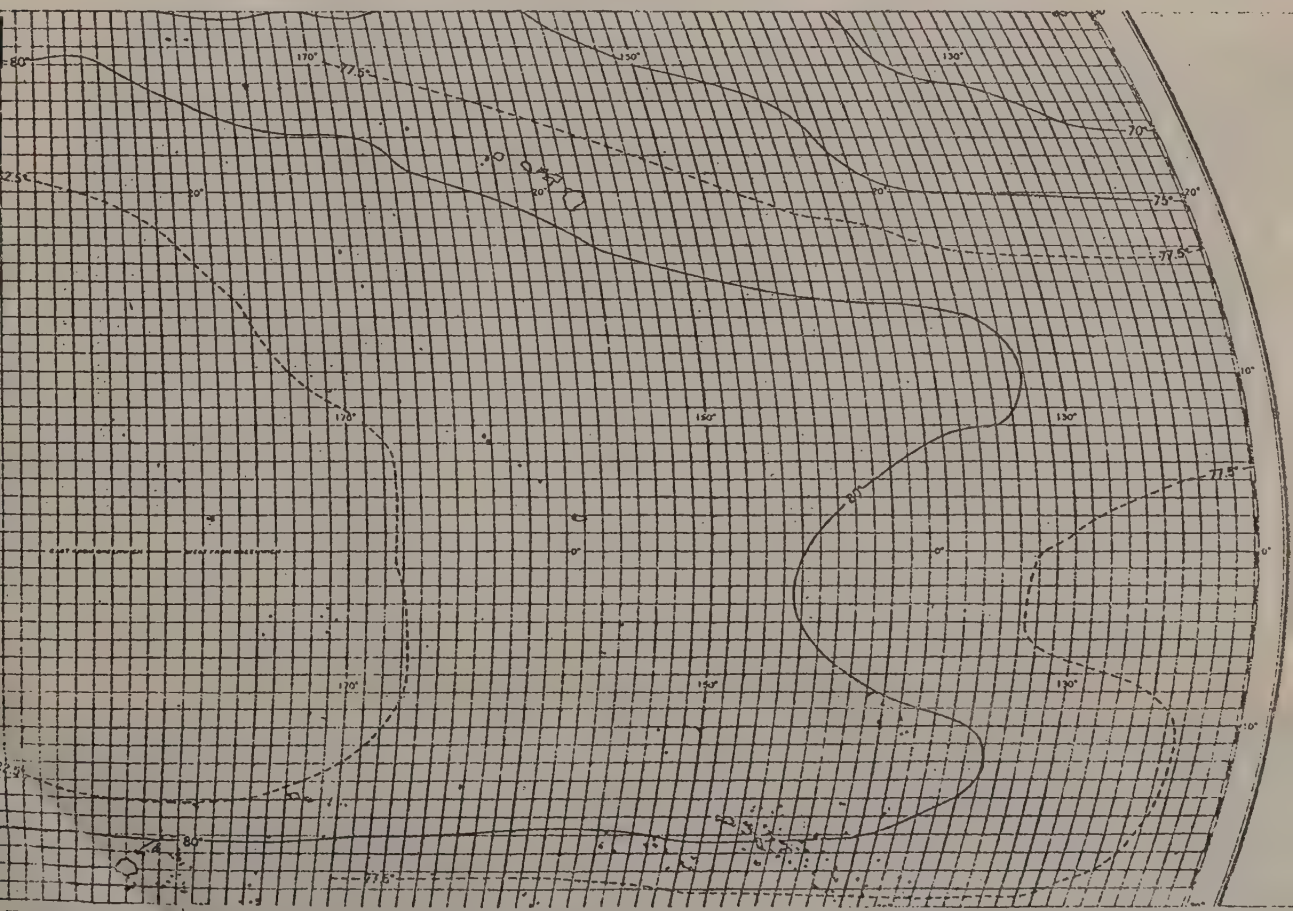


Figure 27j.—Surface temperature in the central equatorial Pacific Ocean in October (from U. S. Navy Hydrographic Office 1944).

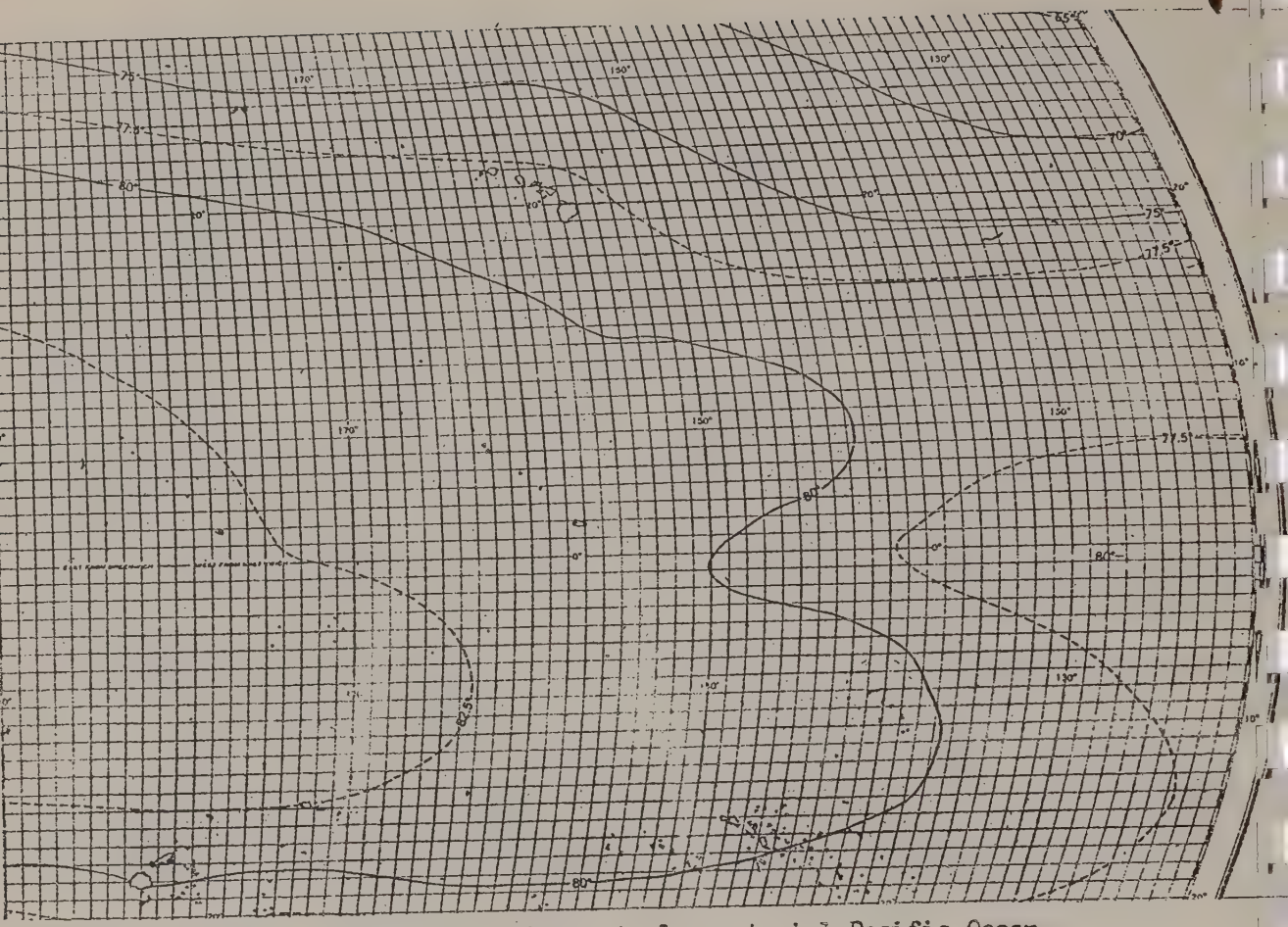


Figure 27k.--Surface temperature in the central equatorial Pacific Ocean in November (from U. S. Navy Hydrographic Office 1944).

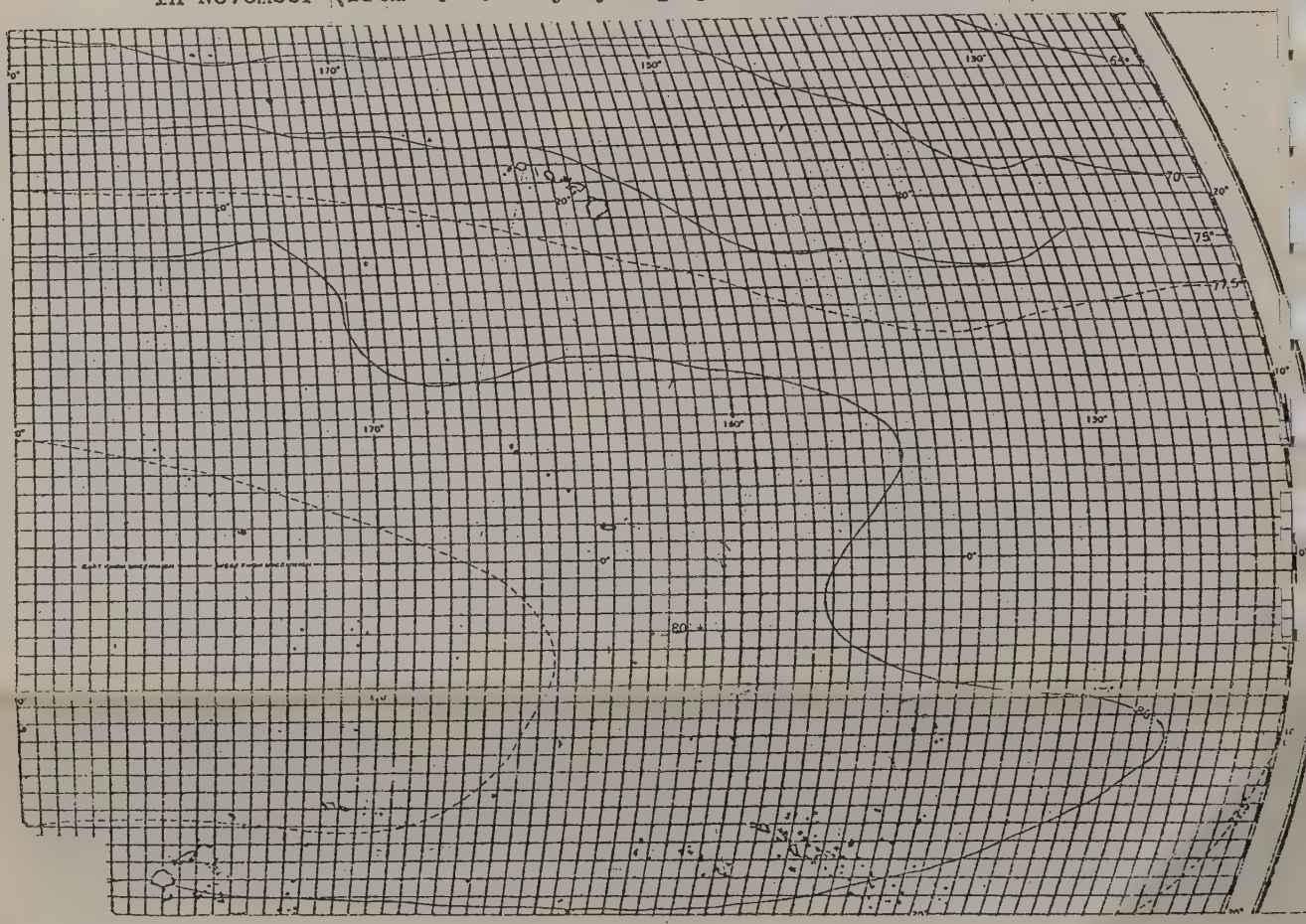


Figure 27ℓ.--Surface temperature in the central equatorial Pacific Ocean in December (from U. S. Navy Hydrographic Office 1944).

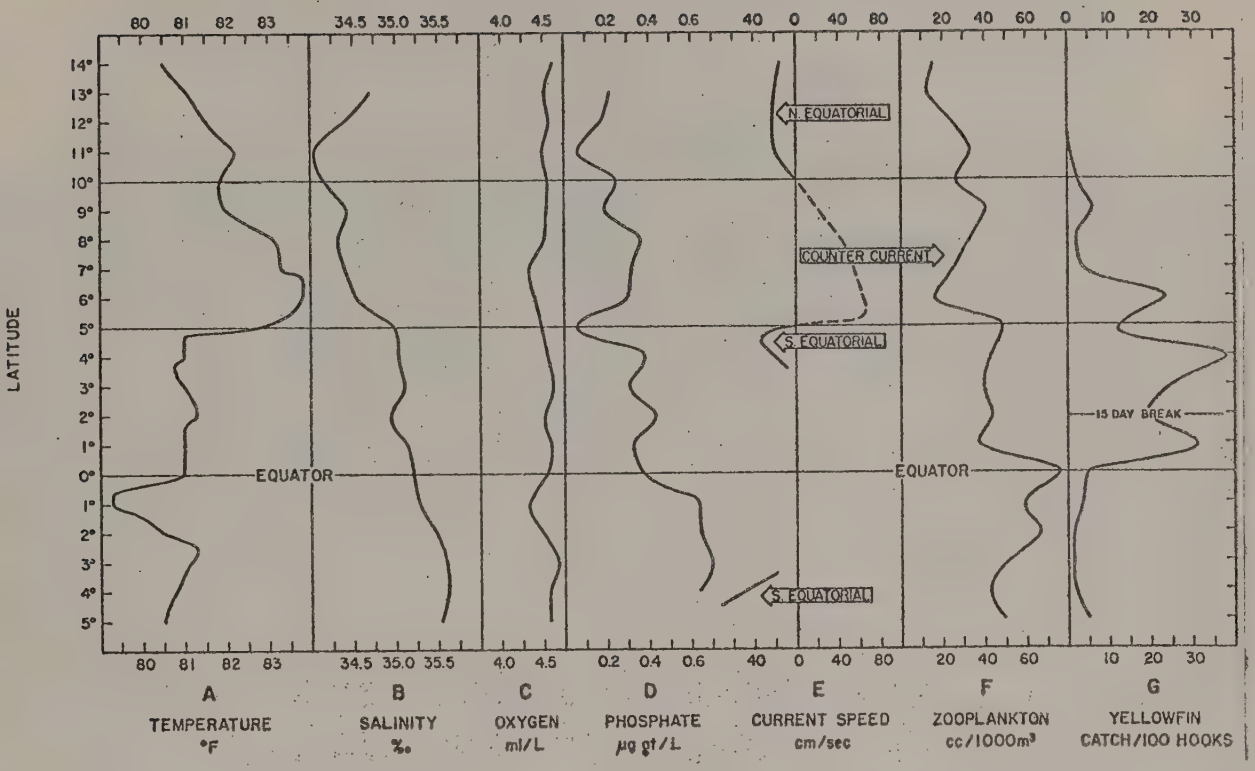


Figure 28.--Summary of various oceanographic and biological data, Hugh M. Smith cruise 11, August-October 1951. Northbound section, panels (A) through (F), southbound section panel (G) (from Austin 1954a).

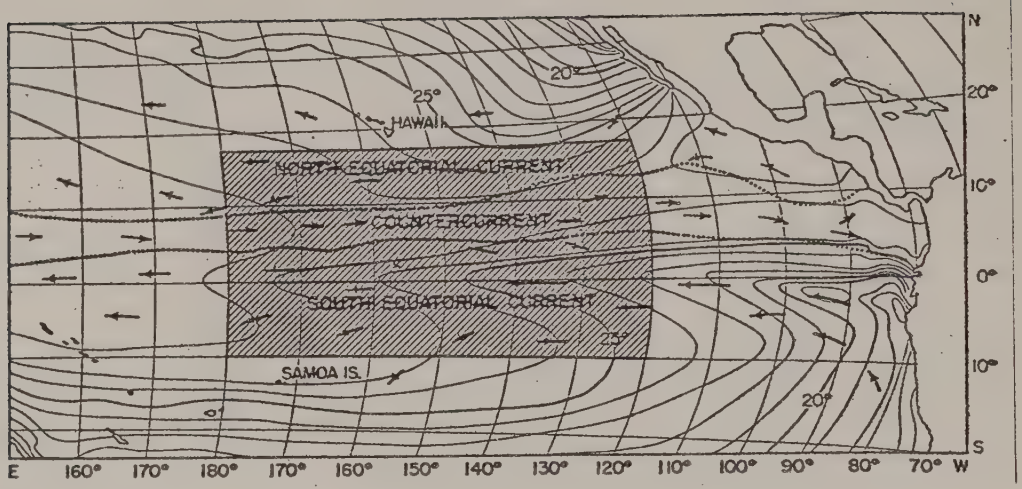


Figure 29.--Schematic representation of the major surface currents and surface isotherms in the central and eastern equatorial Pacific. The area most intensively surveyed is shaded. Arrows denote approximate current direction (adapted from Schott 1935 by Murphy and Shomura 1972).

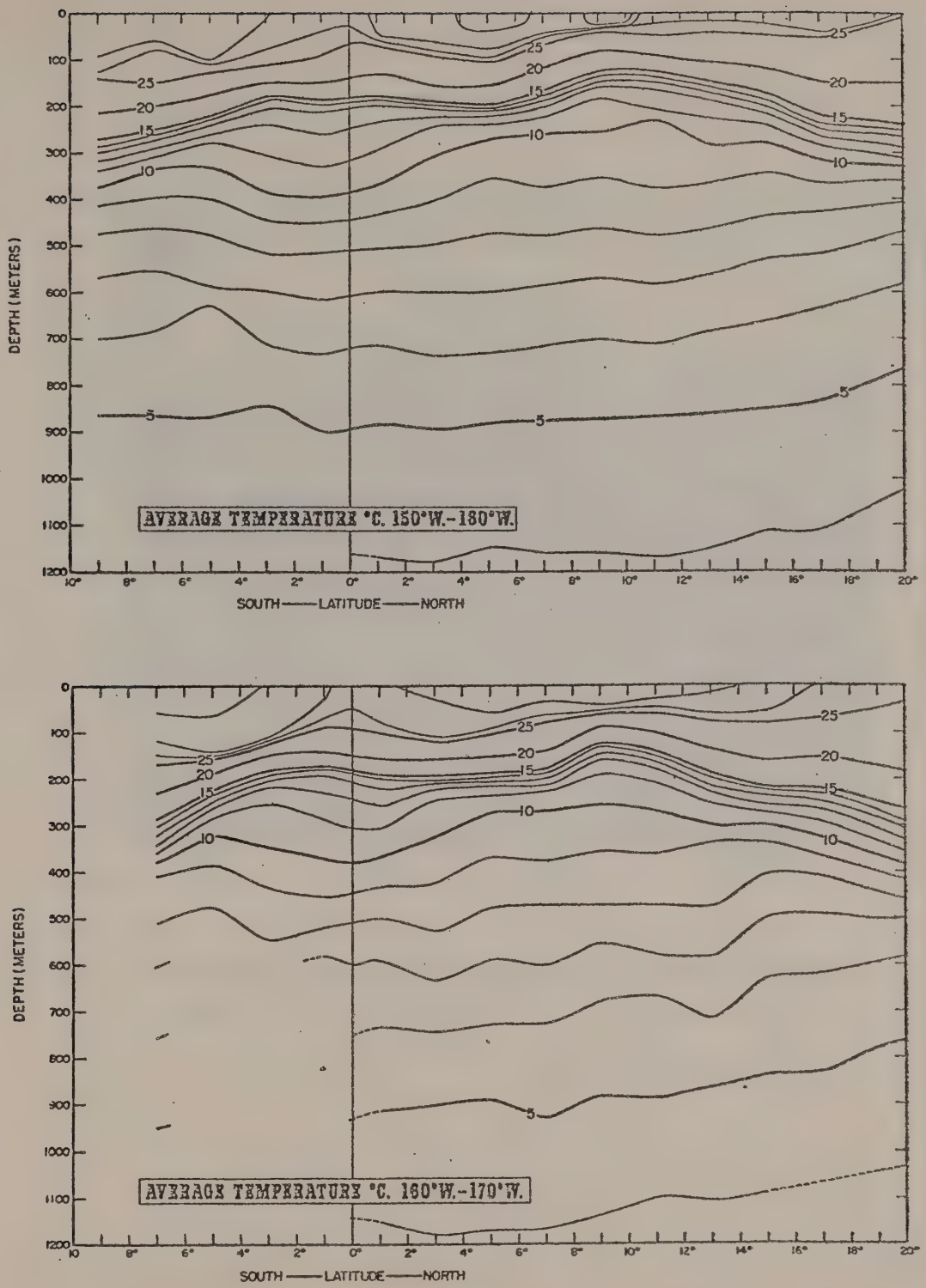


Figure 30.--Meridional temperature sections, based on average values in areas of 2° of latitude by 10° of longitude (from Barkley 1962, see footnote 3).

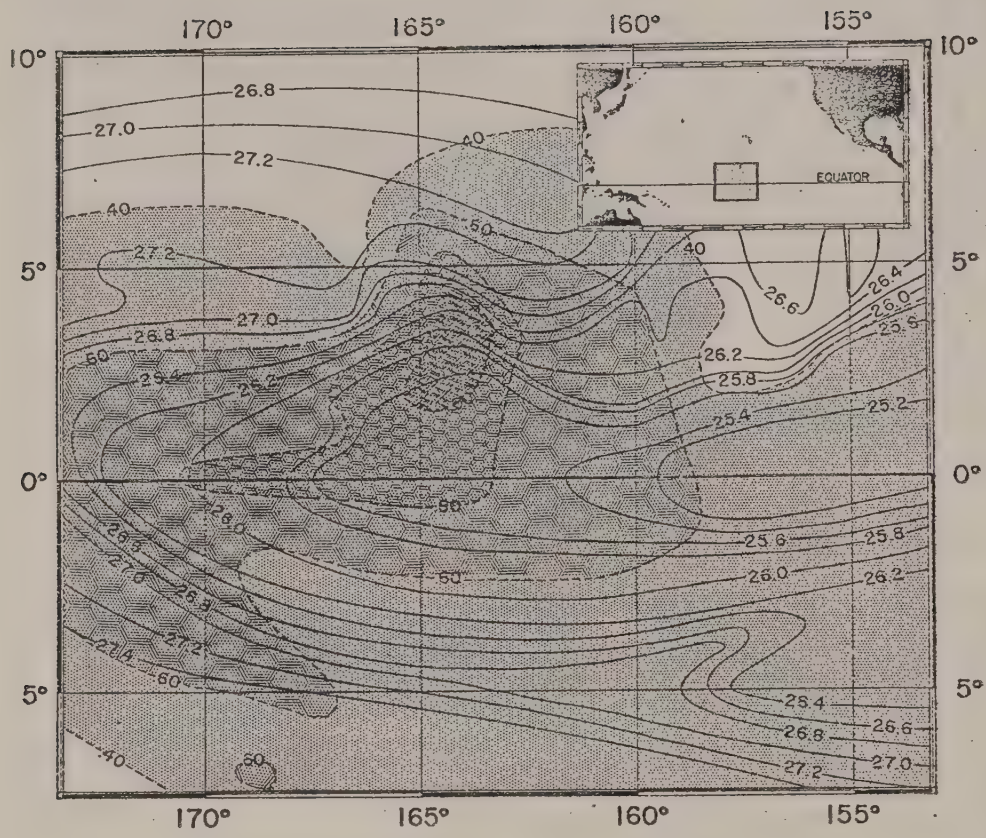


Figure 31.--Surface temperature and variation in phosphate (indicated by shading) in the central equatorial Pacific Ocean (Sette and staff 1954).

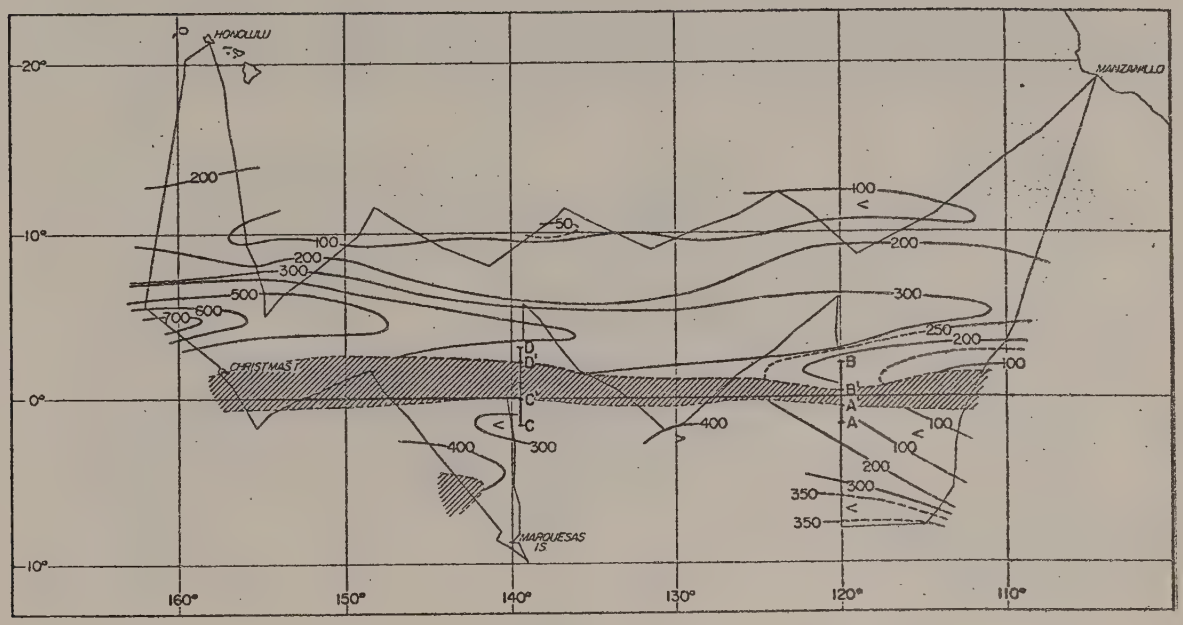


Figure 32.--Depth of the thermocline as determined from the BT September-December 1955.

data,/ The shaded section is the region where thermocline depth could not be determined objectively, because the BT trace showed either more than one inflection or a continuous negative gradient from the surface to the maximum depth of the trace (from Austin 1960).

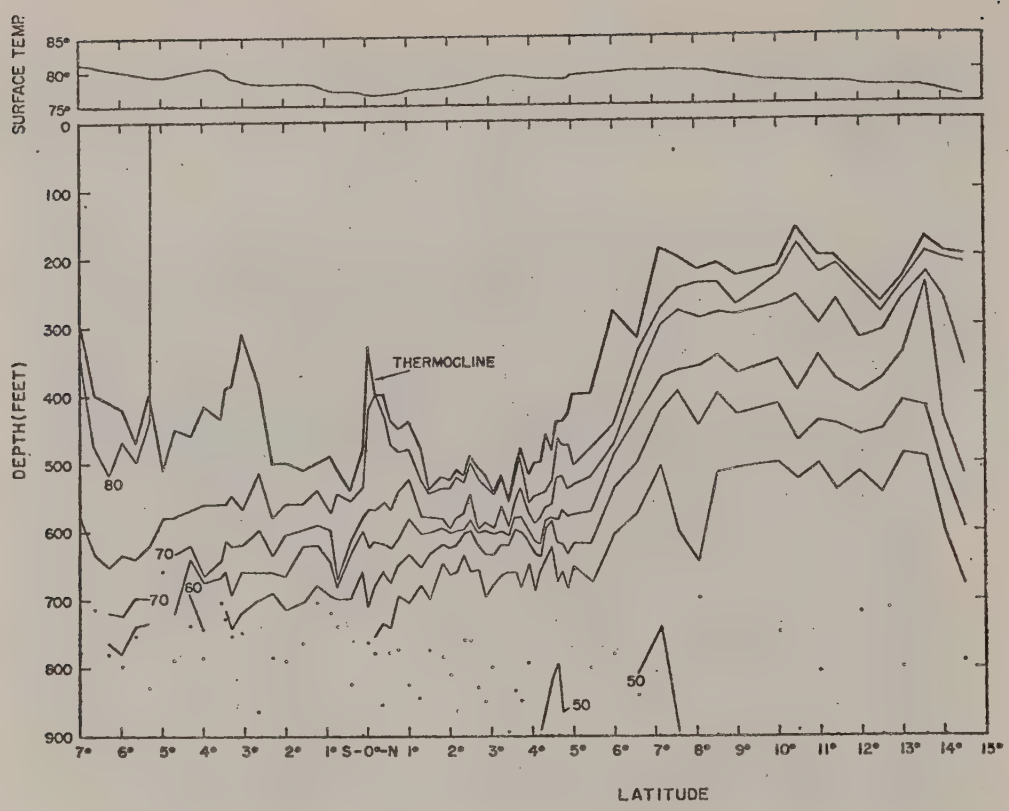


Figure 33.--Above, surface temperature and below, temperature section based on BT data along long. 158°W, 15-26 January 1951. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. Hugh M. Smith cruise 8 (from Cromwell 1954).

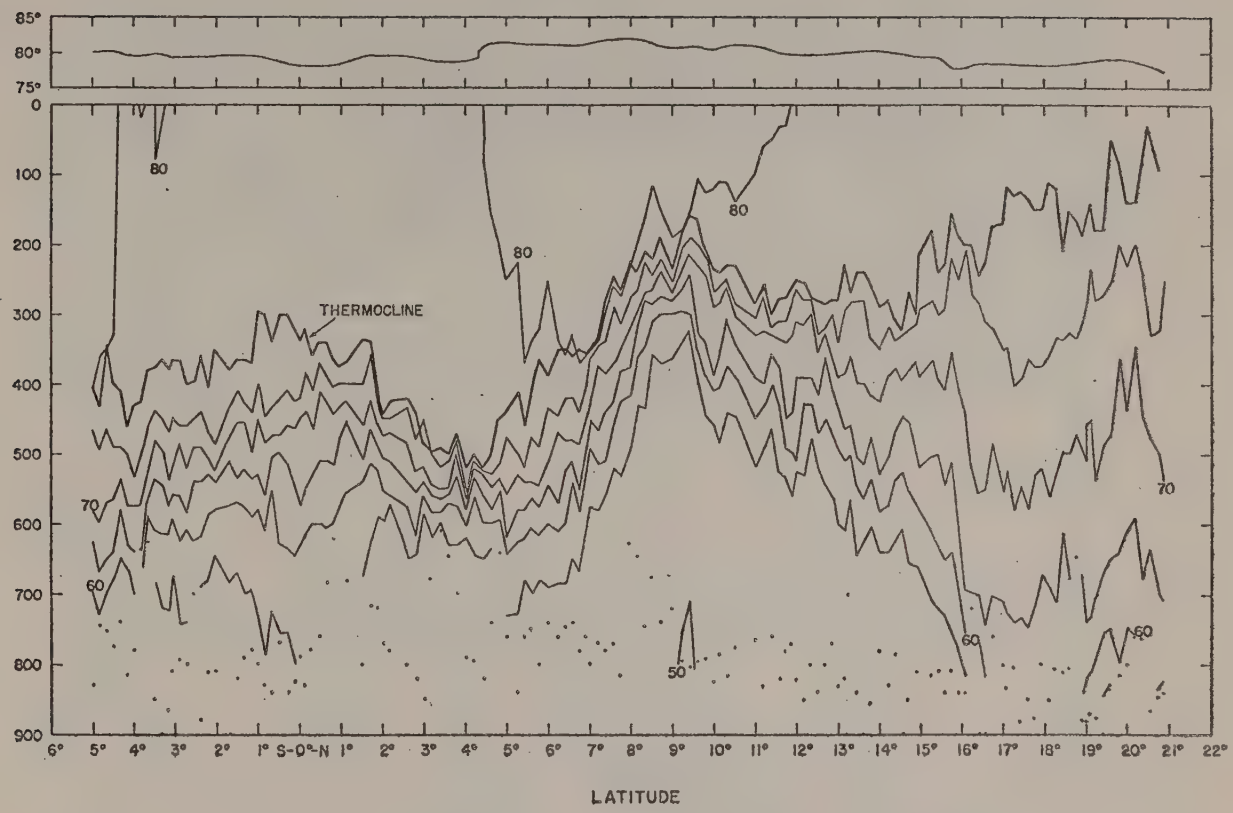


Figure 34.--Above, surface temperature and below, temperature section based on BT data along long. 158°W, 28 July-6 August 1950. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. Hugh M. Smith cruise 5 (from Cromwell 1954).

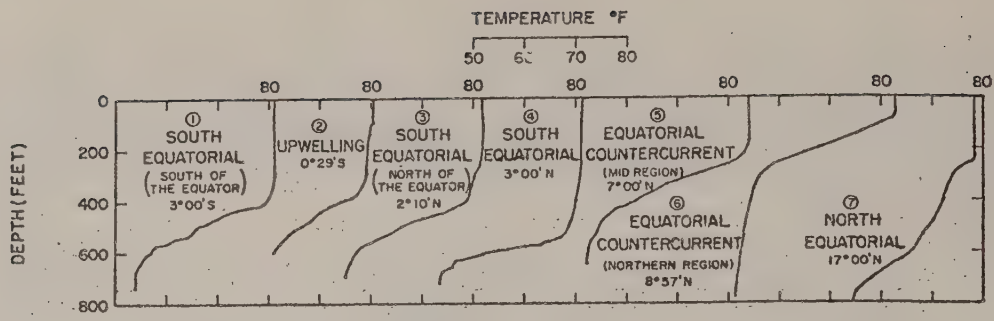


Figure 35.--Typical BT traces for various regions crossed during Hugh M. Smith cruise 11, August-September 1951 (from Austin 1954a).

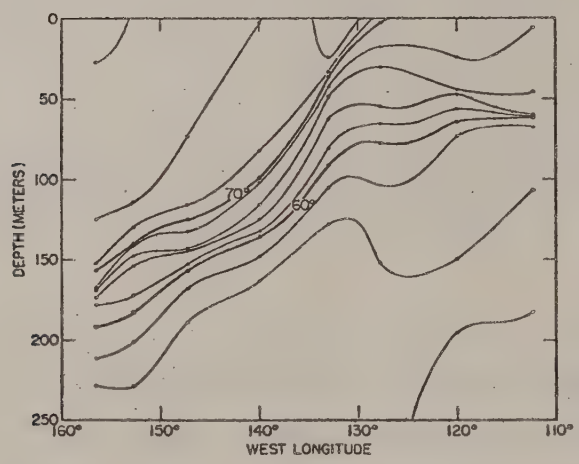


Figure 36.--Vertical temperature (°F) distribution along the equator illustrating the east-west slope of the thermocline, September-December 1955 (from Austin 1960).

JANUARY

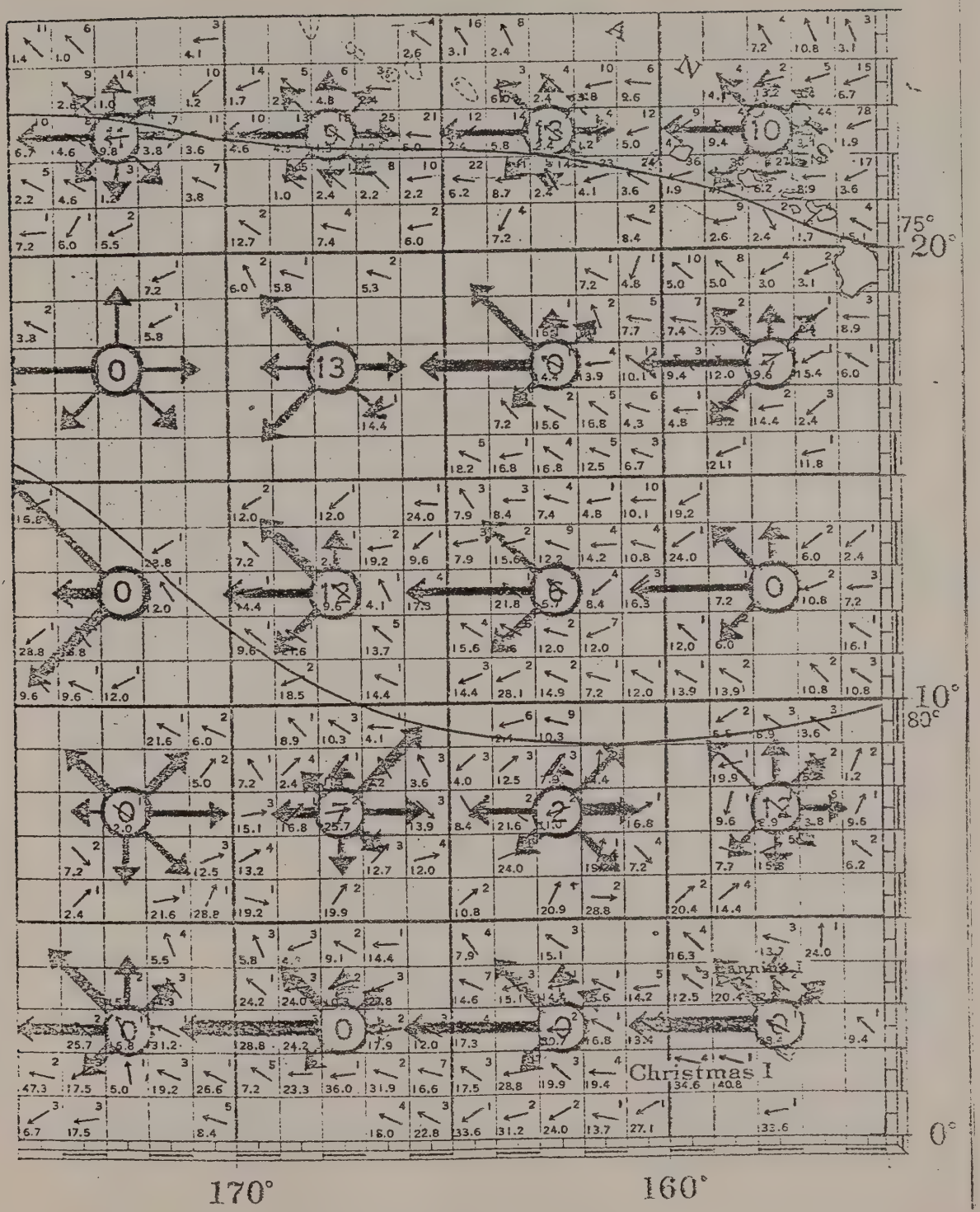


Figure 37a.--Surface drift vectors for January (from U.S. Navy Hydrographic Office 1950).

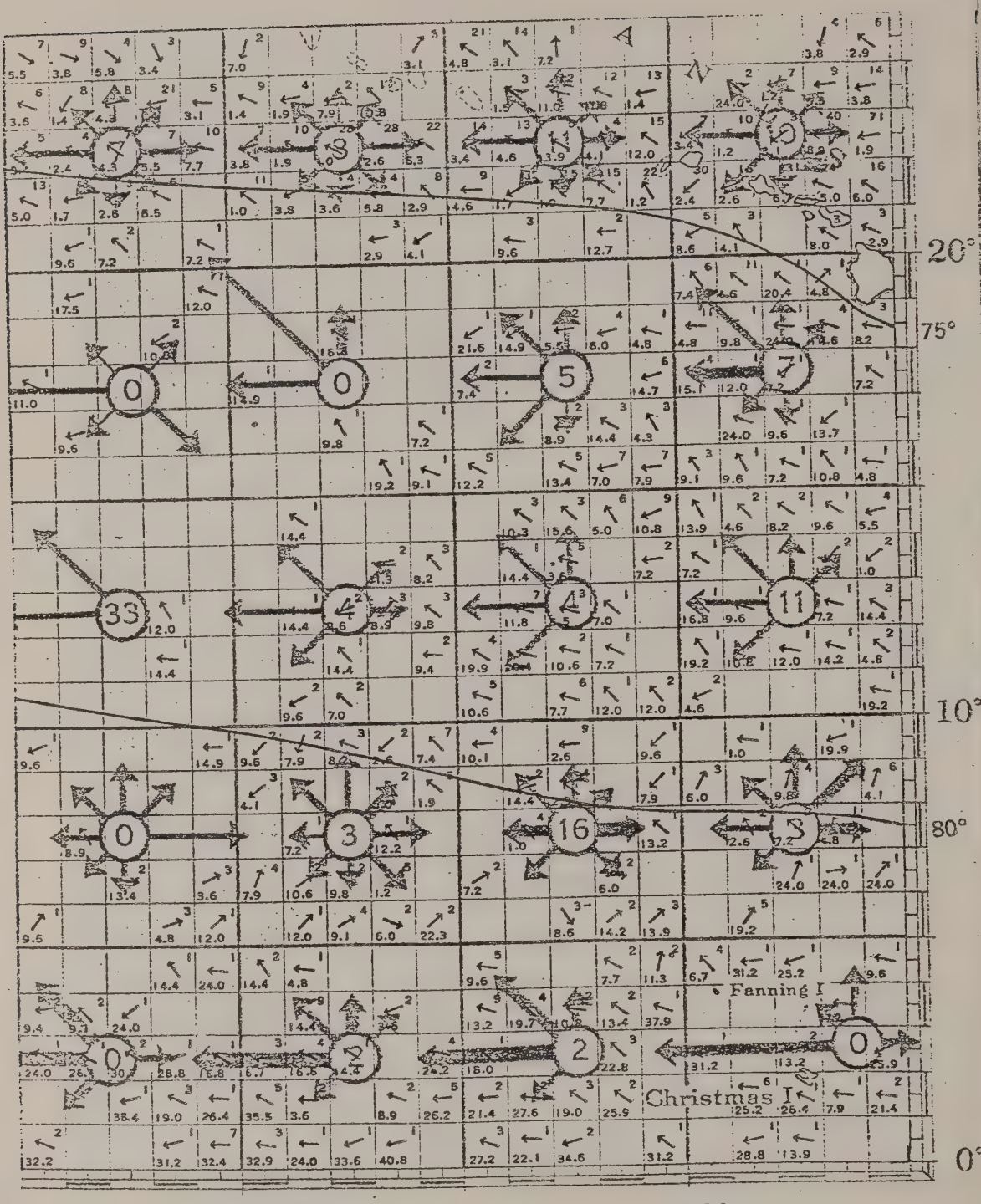


Figure 37b.--Surface drift vectors for February (from U.S. Navy Hydrographic Office 1950).

APRIL

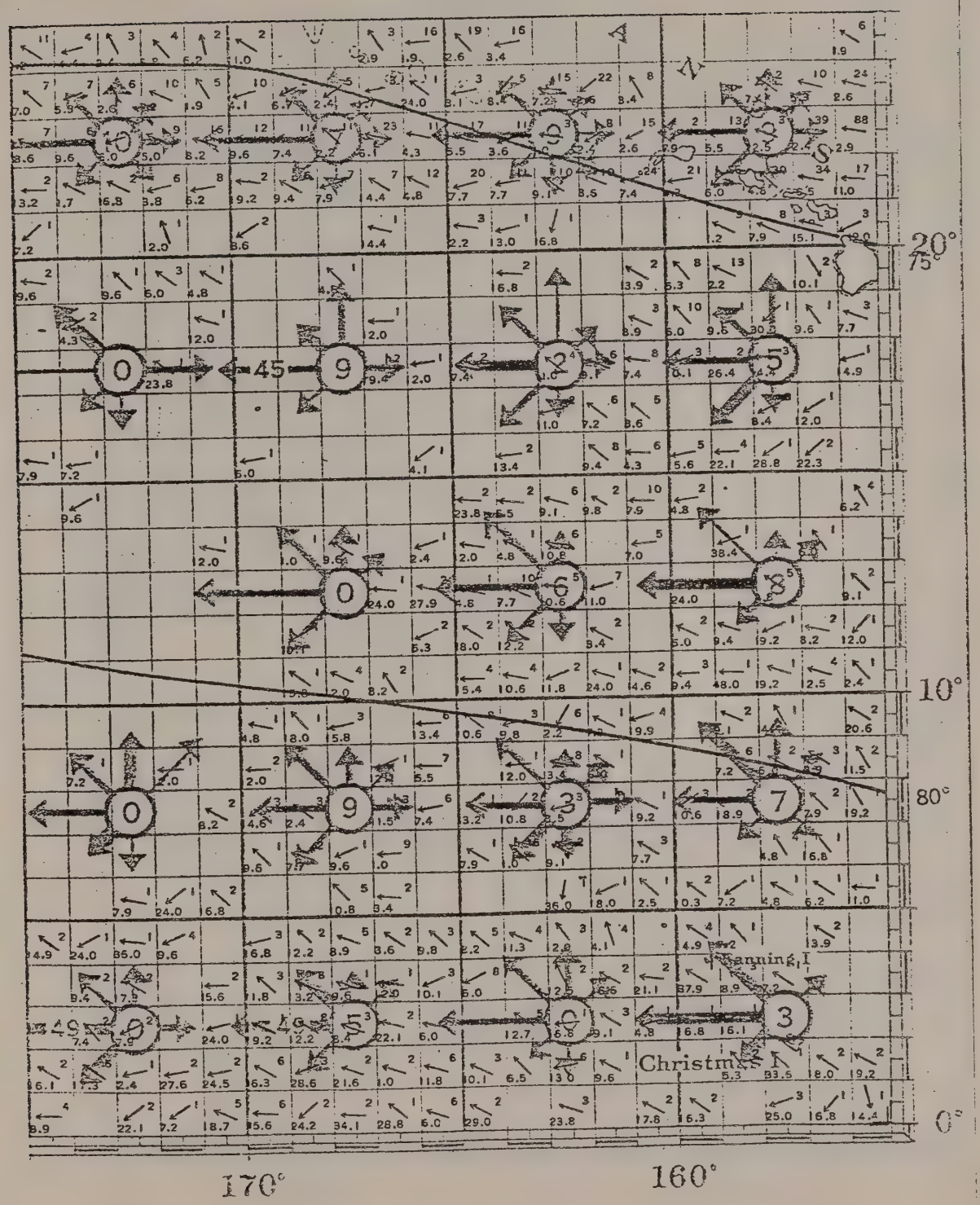


Figure 37d.--Surface drift vectors for April (from U.S. Navy Hydrographic Office 1950).

MARCH

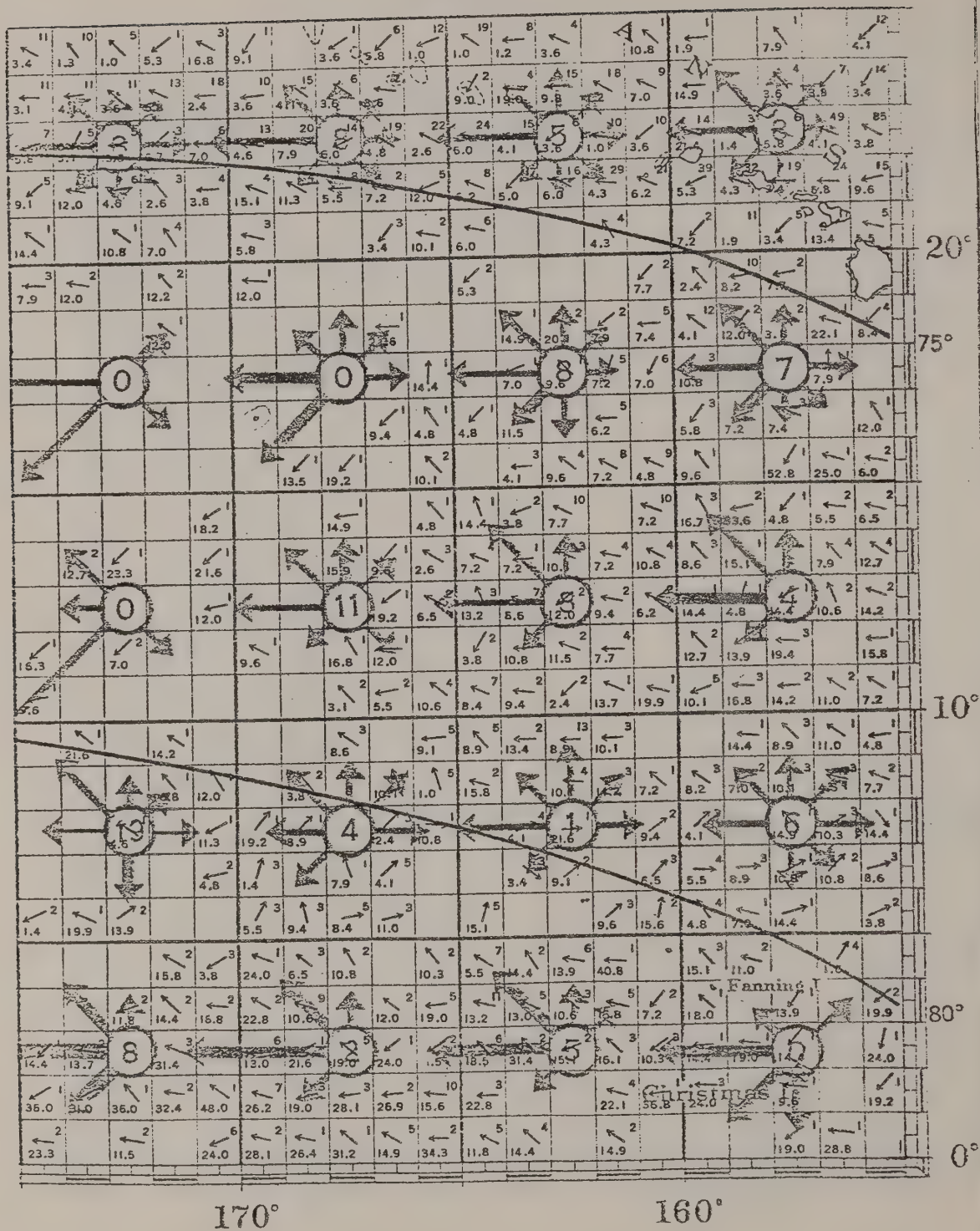


Figure 37c.--Surface drift vectors for March (from U.S. Navy Hydrographic Office 1950).

MAY

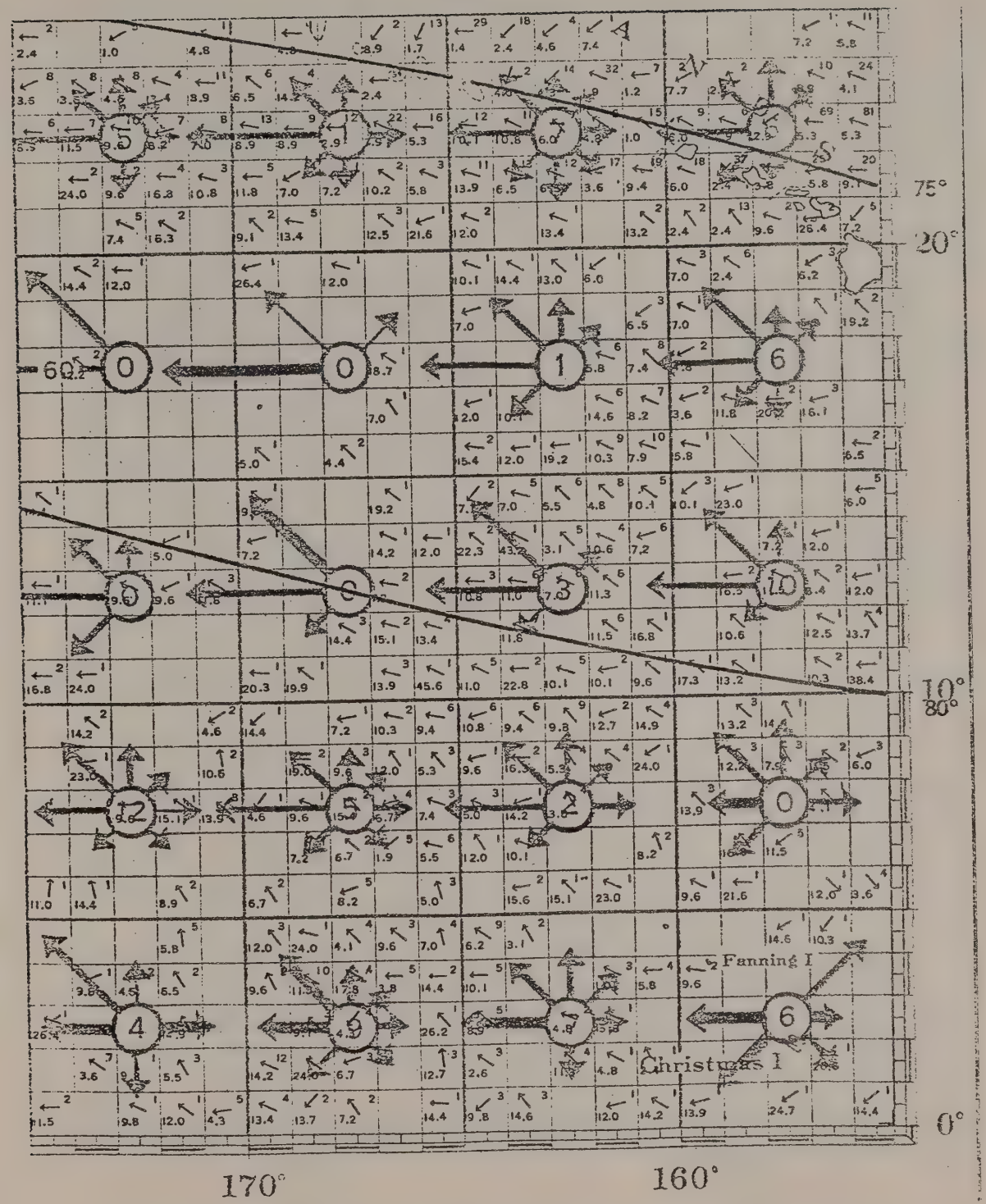


Figure 37e.--Surface drift vectors for May (from U.S. Navy Hydrographic Office 1950).

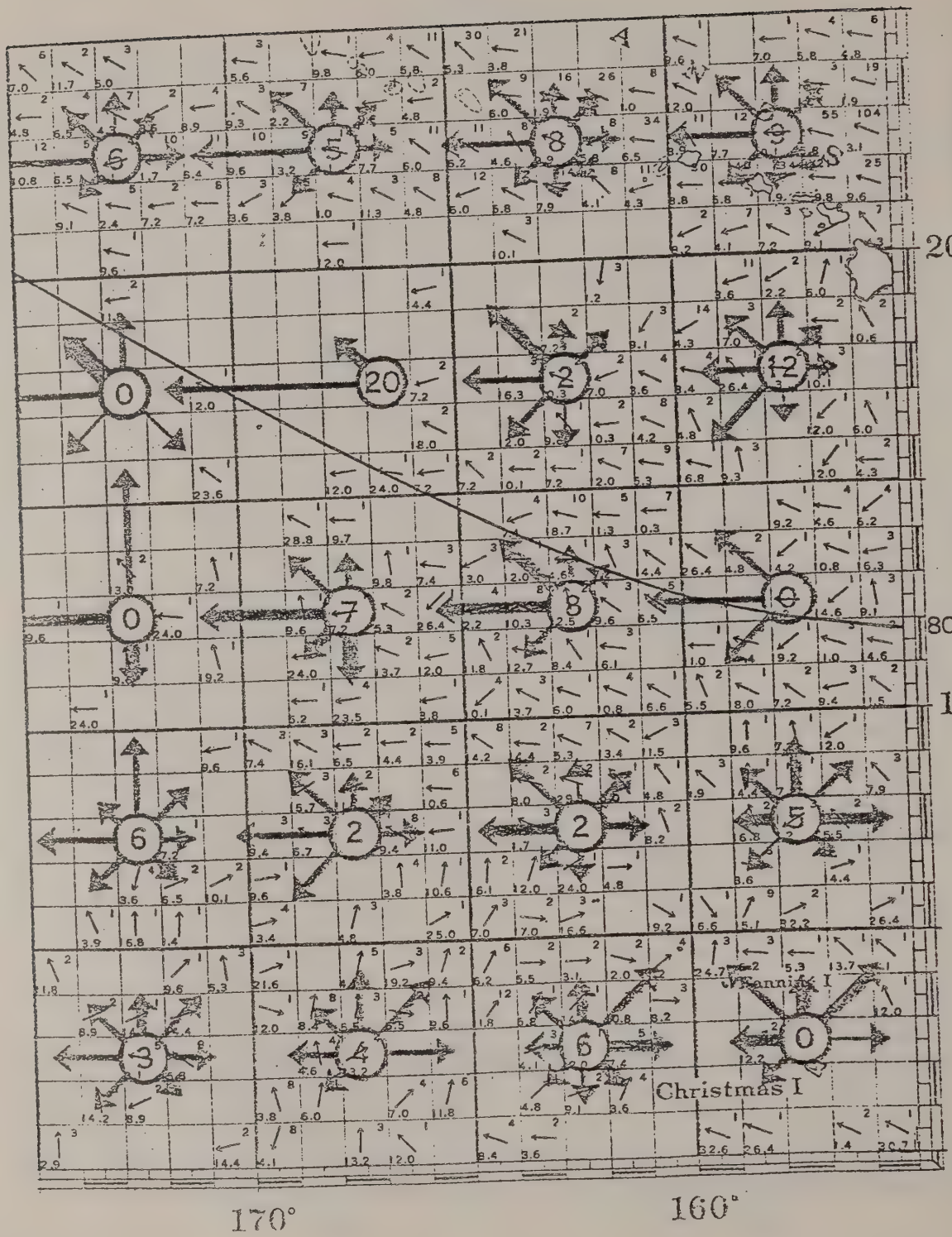


Figure 37f.--Surface drift vectors for June (from U.S. Navy Hydrographic Office 1950).

JULY

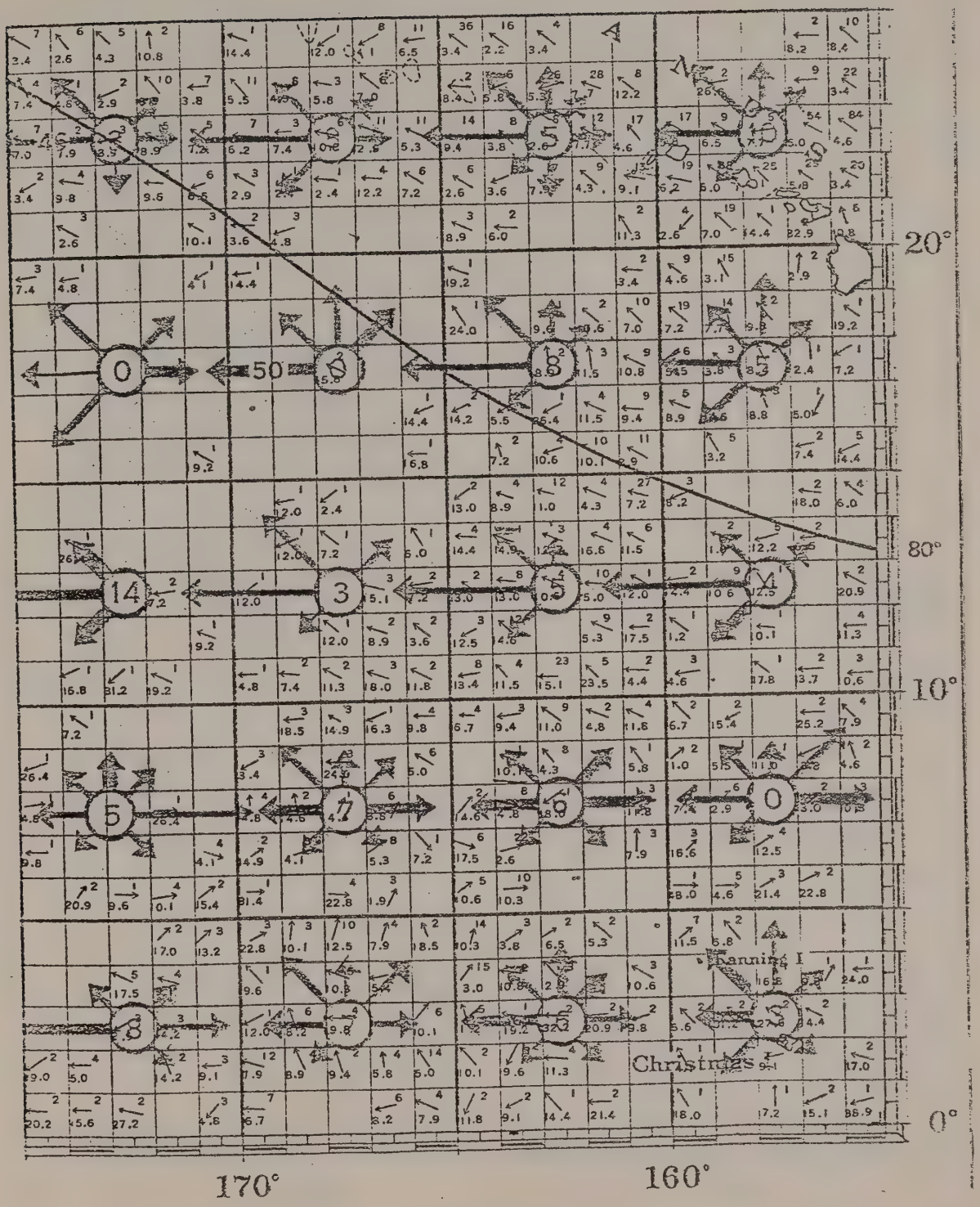


Figure 37g.--Surface drift vectors for July (from U.S. Navy Hydrographic Office 1950).

AUGUST

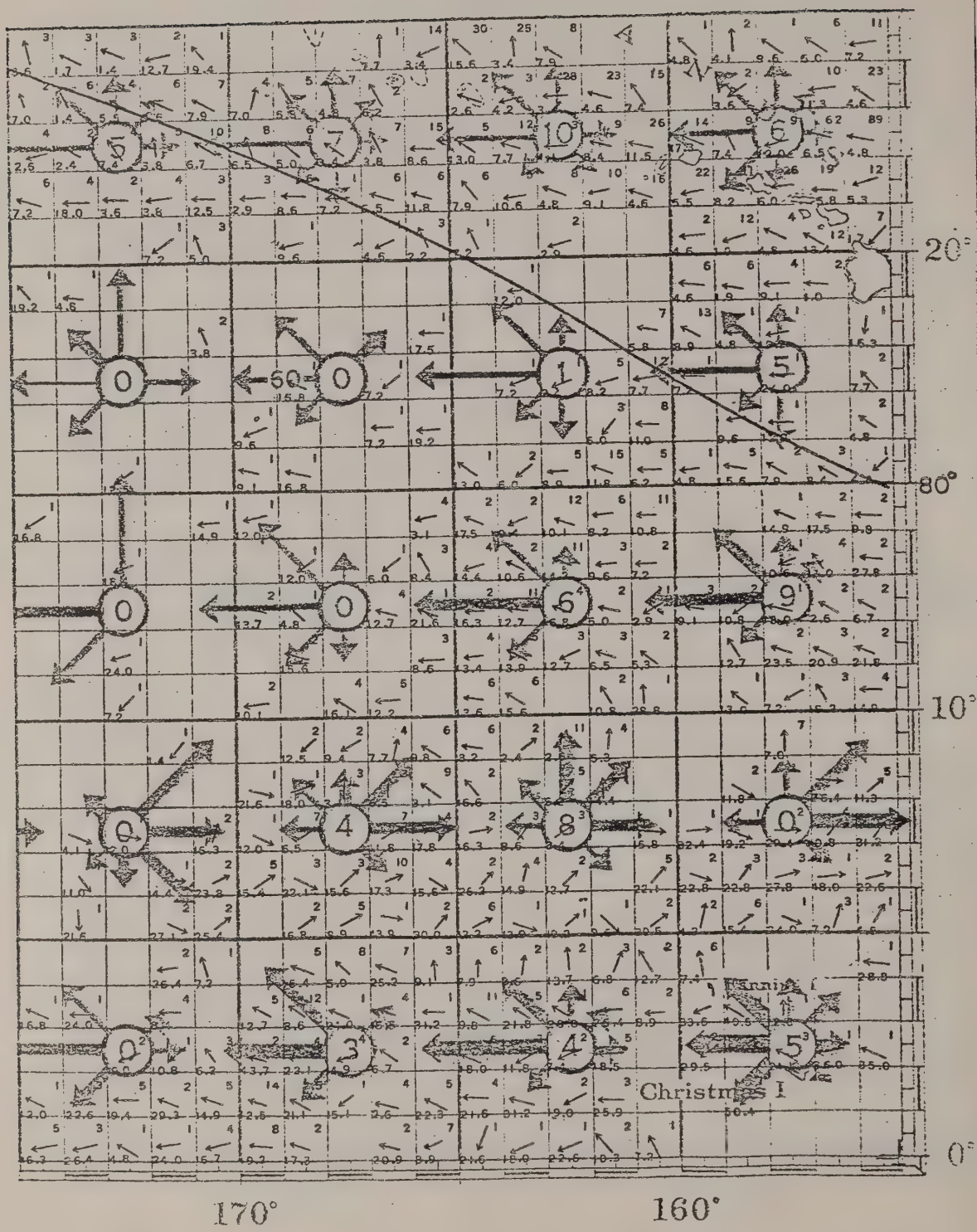


Figure 37h.--Surface drift vectors for August (from U.S. Navy Hydrographic Office 1950).

SEPTEMBER

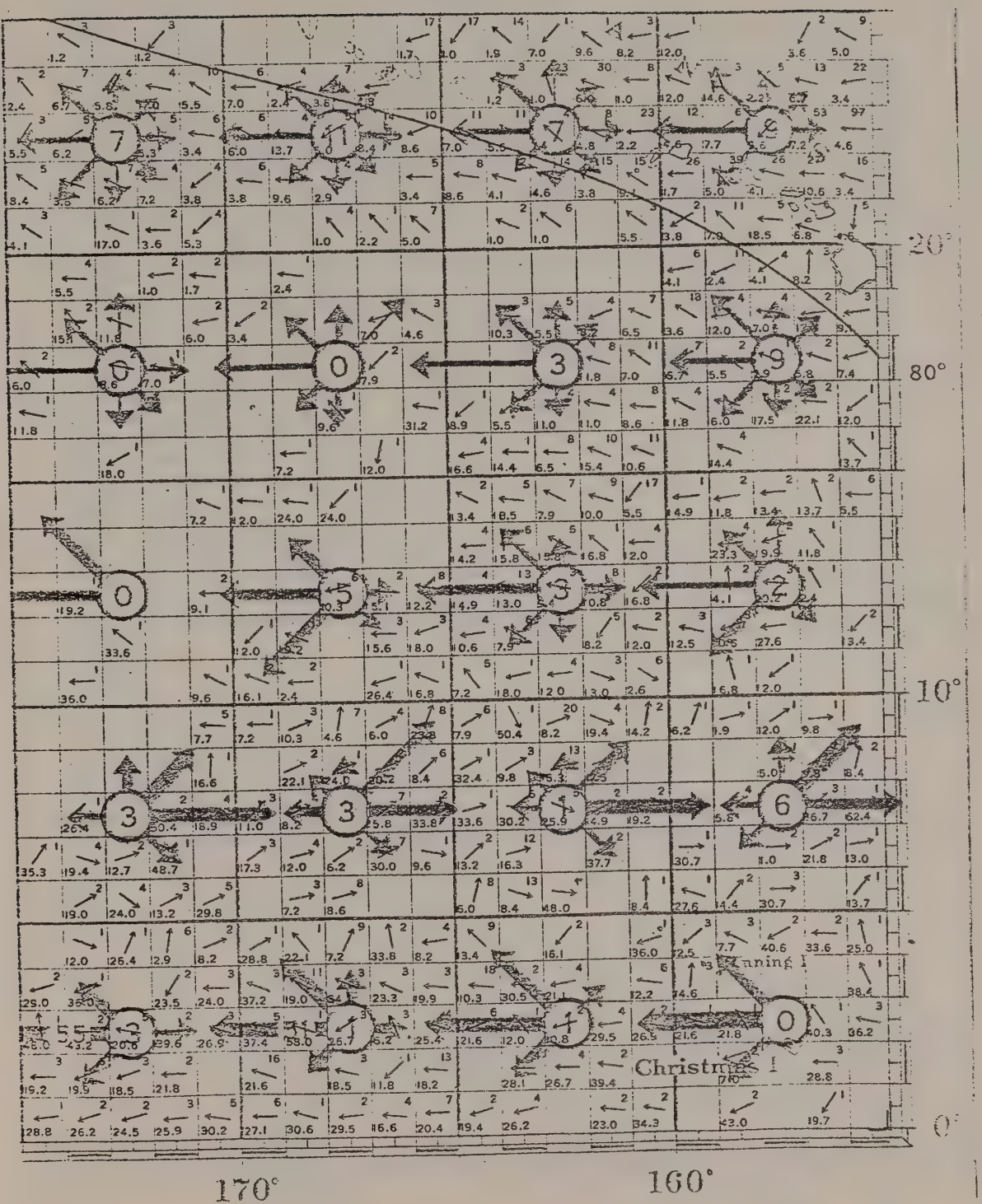


Figure 37i.--Surface drift vectors for September (from U.S. Navy Hydrographic Office 1950).

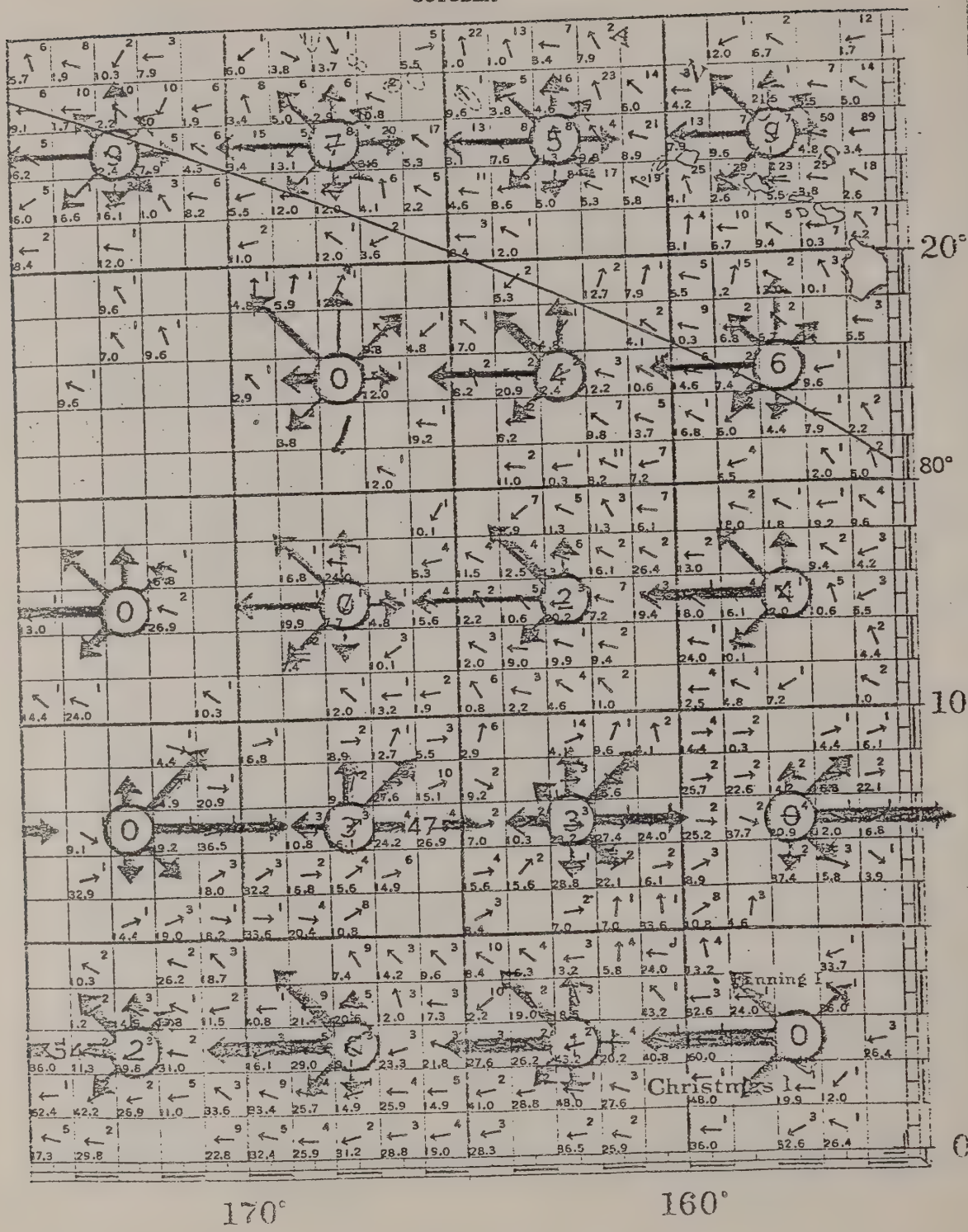


Figure 37j.--Surface drift vectors for October (from U.S. Navy Hydrographic Office 1950).

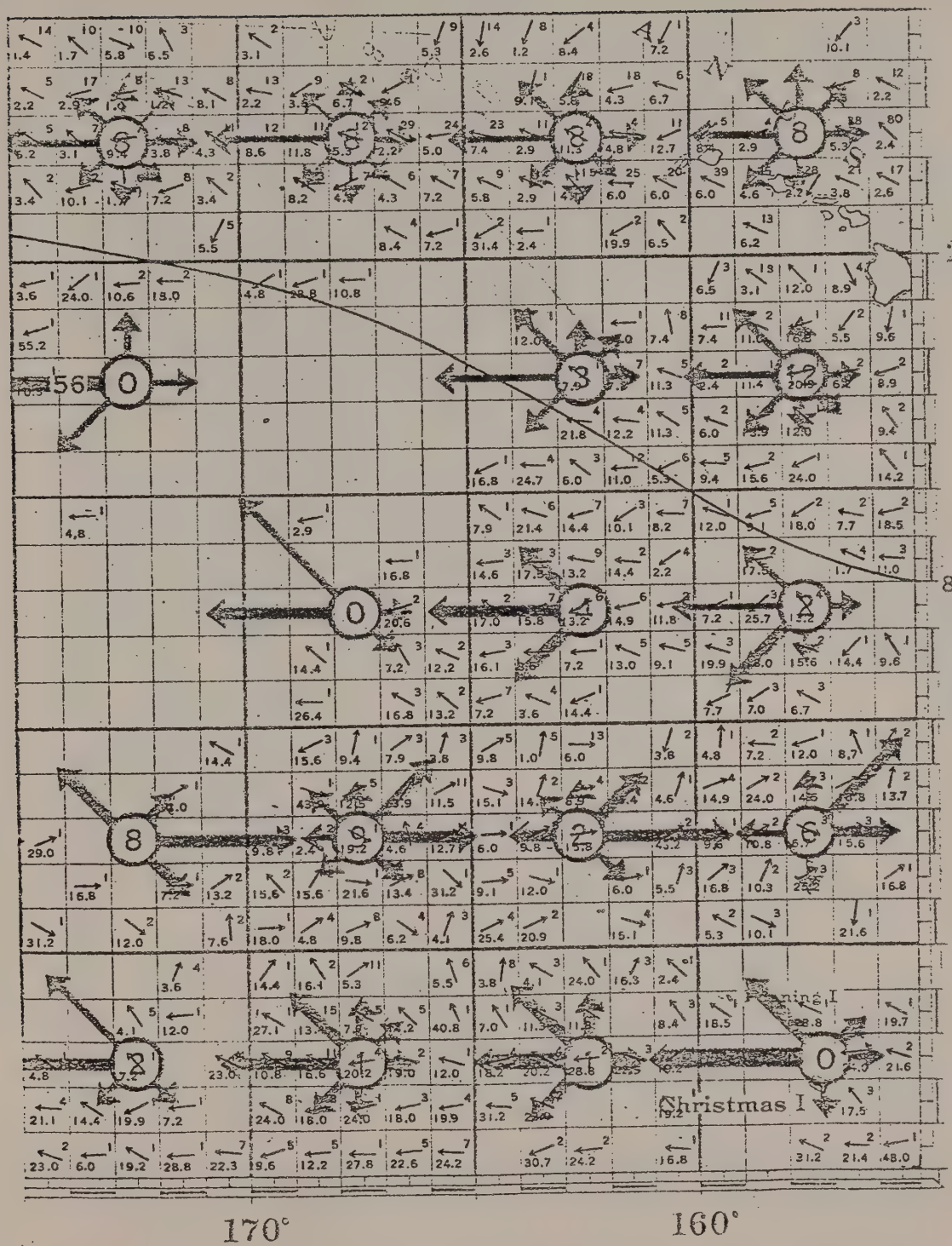


Figure 37k.--Surface drift vectors for November (from U.S. Navy Hydrographic Office 1950).

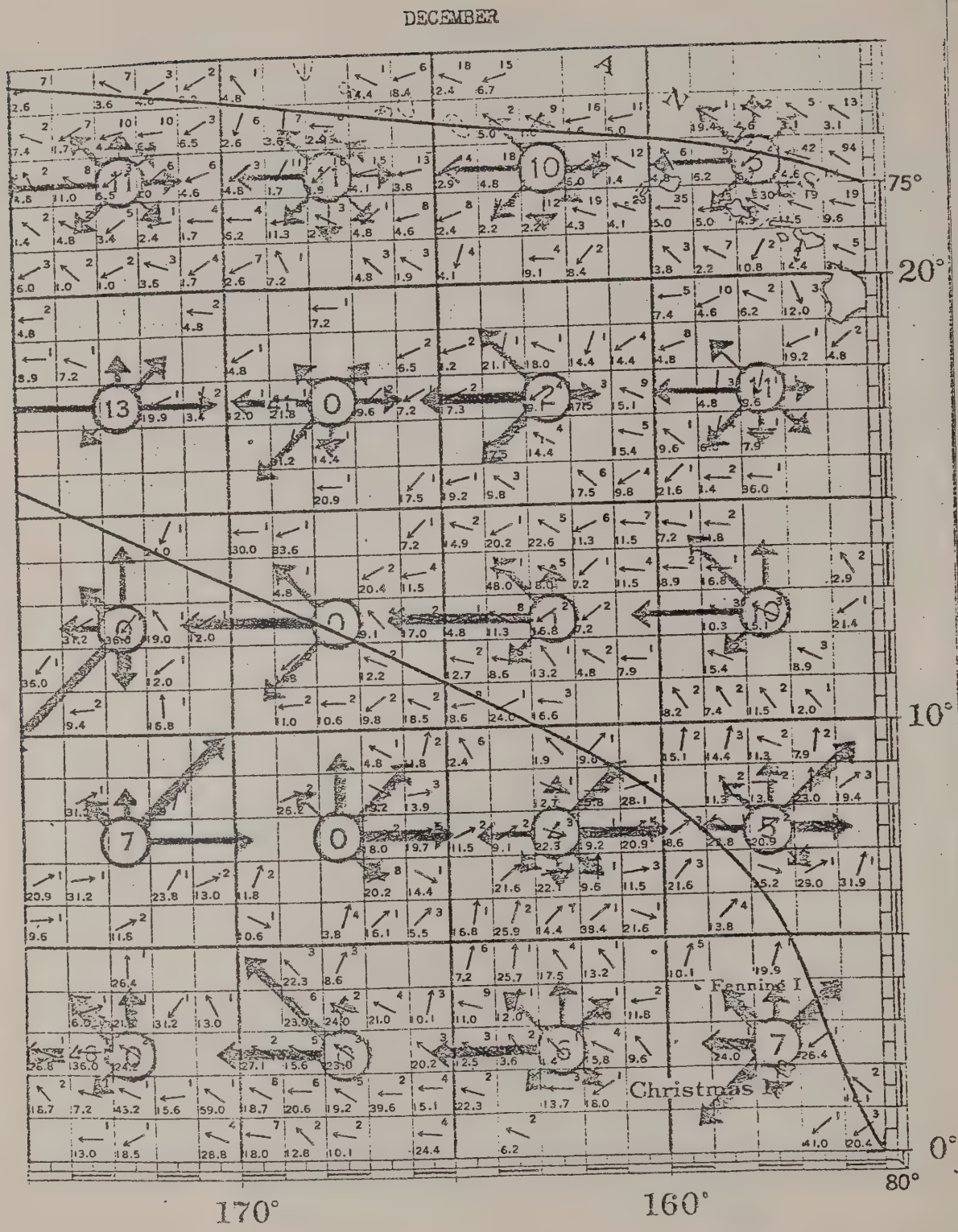


Figure 37ℓ.--Surface drift vectors for December (from U.S. Navy Hydrographic Office 1950).

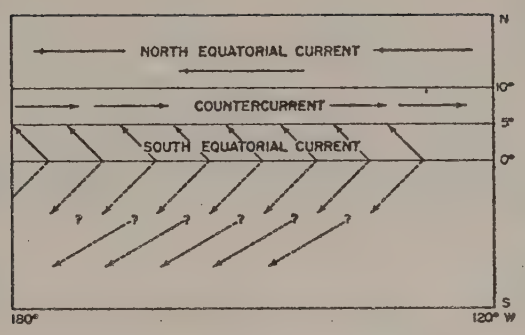


Figure 38.--Schematic view of the equatorial current system incorporating recent empirical determinations of flow north of the equator. Flow south of the equator is indicated as questionable (from Murphy and Shomura 1972).

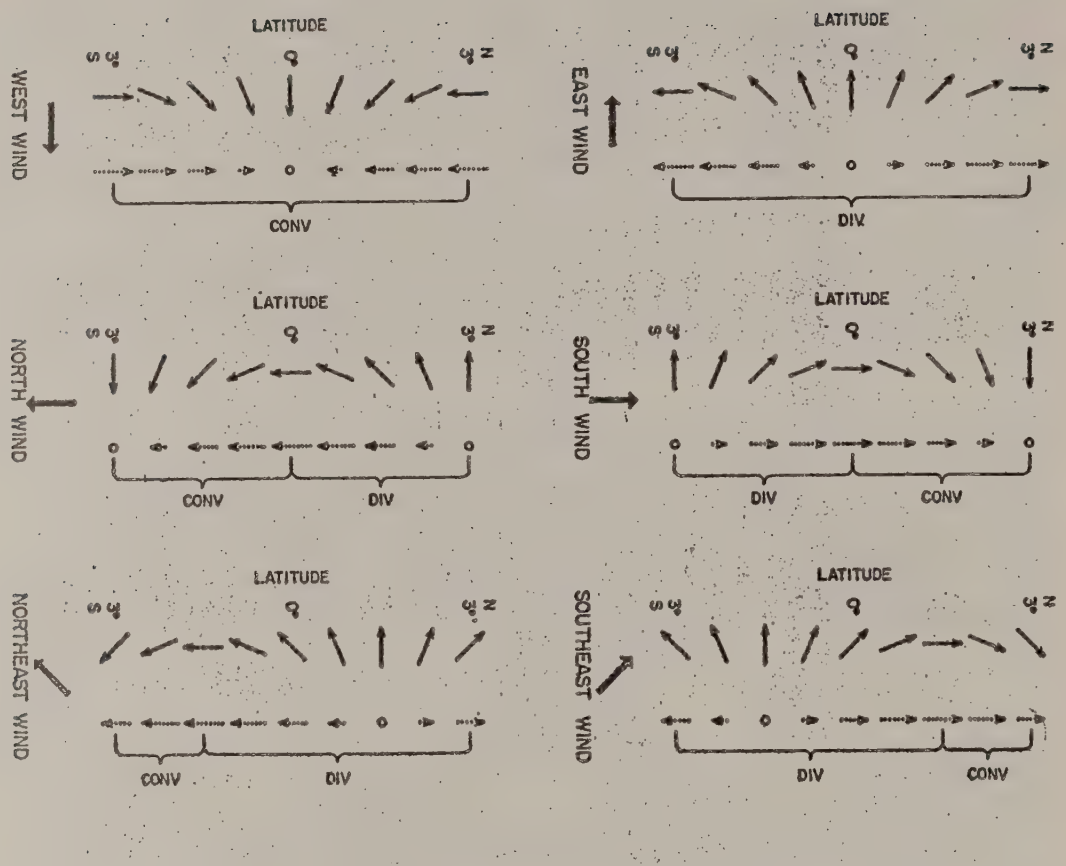


Figure 39.--Directions of current transport (solid arrows) which would exist near the equator under various wind conditions if there were no pressure-gradient force acting. The current magnitude is drawn everywhere constant (solid arrows). For each wind condition the meridional components of the current transport (dotted arrows) are drawn to emphasize the regions of meridional divergence (Div.) and convergence (Conv.) (from Cromwell 1953).

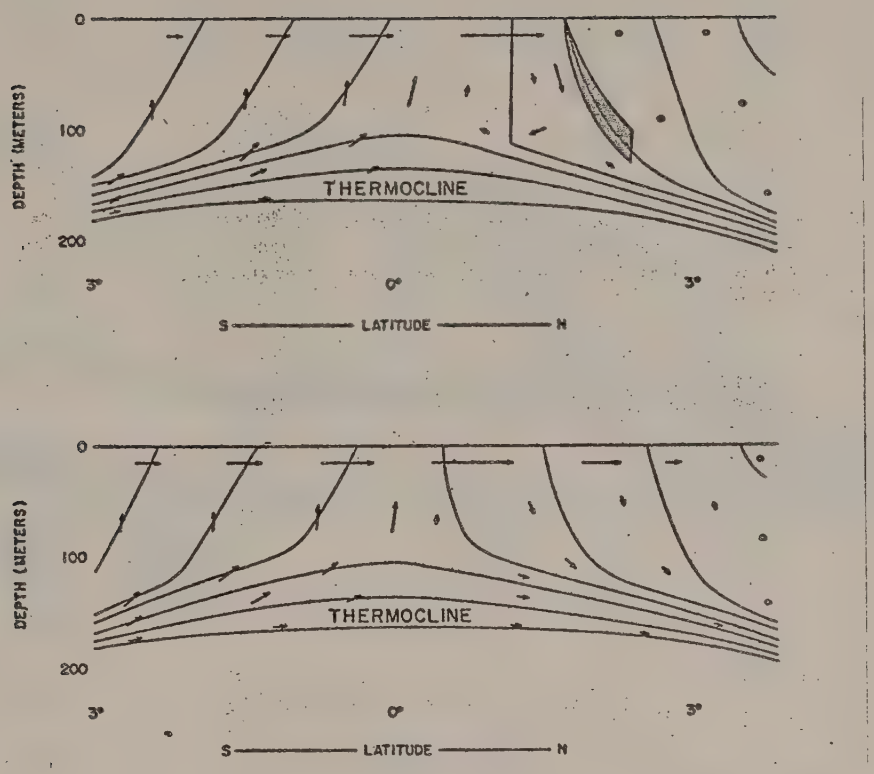


Figure 40.--Schematic representation of circulation in the meridional plane near the equator during a southeast wind when front is present (below). The arrows have the character of streamlines and do not represent trajectories. The arrow shaft lengths indicate roughly the relative magnitudes of flow. Small circles indicate regions of slight and variable flow in this plane. The shaded zone in the upper diagram represents an equatorial front (Cromwell 1953).

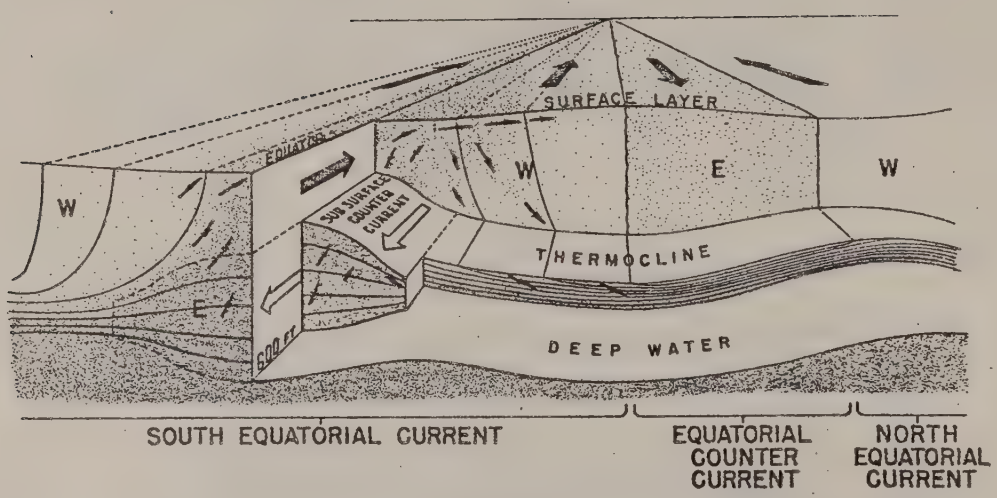


Figure 41.--Concept of equatorial circulation along long. 150°W. The surface currents are shown by broad arrows; the vertical temperature structure by the fine lines of equal temperature (from Sette and staff 1954).

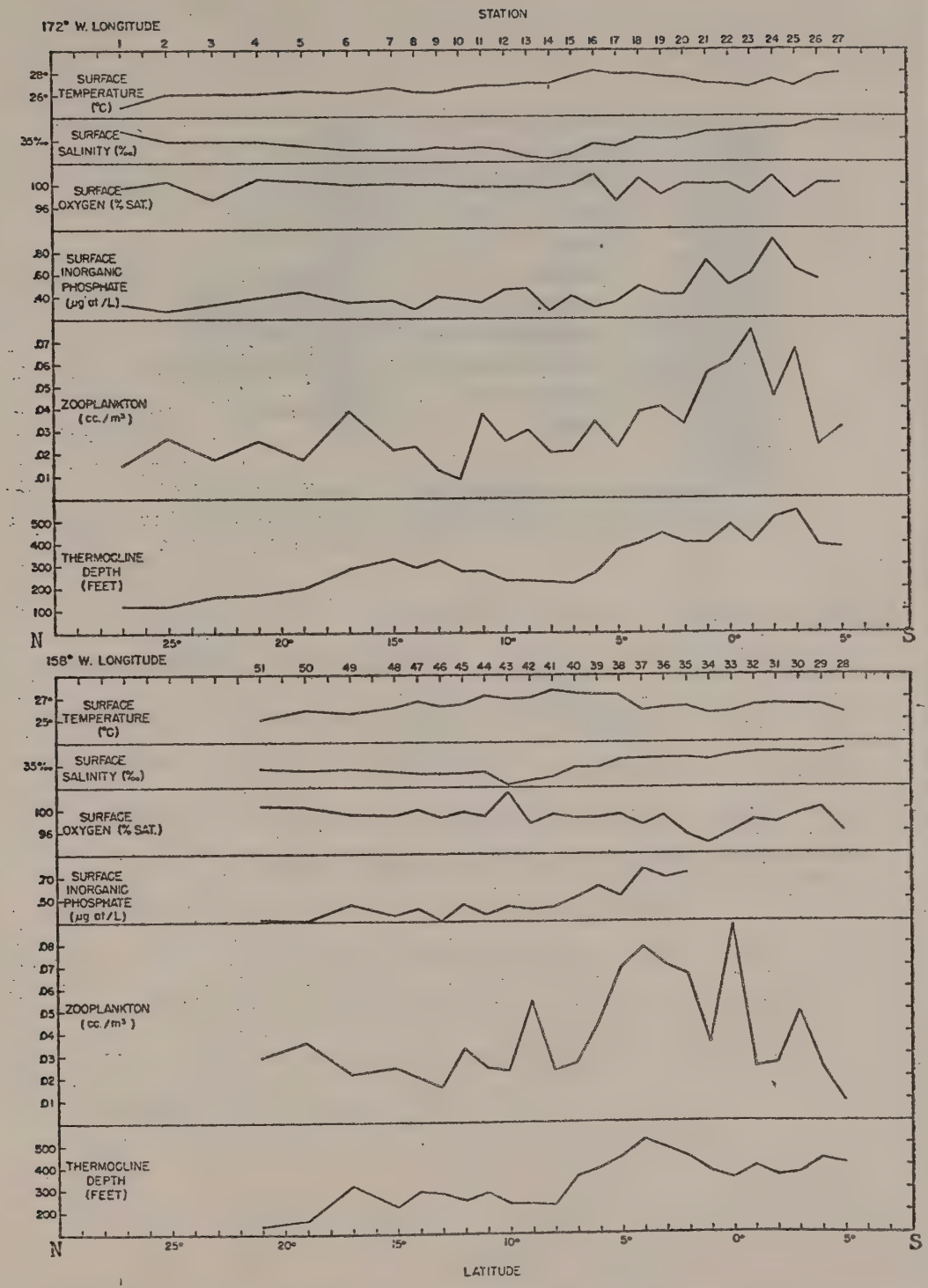


Figure 42.--Variations in temperature, salinity, oxygen, inorganic phosphate, thermocline depth, and zooplankton volume along long. 158° and 172°W as found on Hugh M. Smith cruise 5, June-August 1950 (from King and Demond 1953).

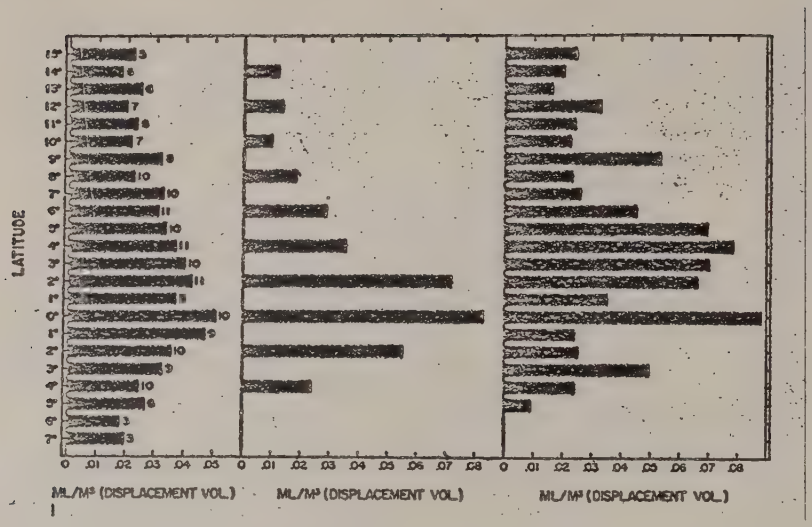


Figure 43.--Left: Zooplankton data from 11 crossings of the equatorial currents between long. 140°W and 180°, combined grossly without regard for longitude or season. The number of observations included in the averaging for each degree of latitude appear at the right. Middle and right: Zooplankton data concurrent with the hydrographic sections examined by Cromwell (1953).

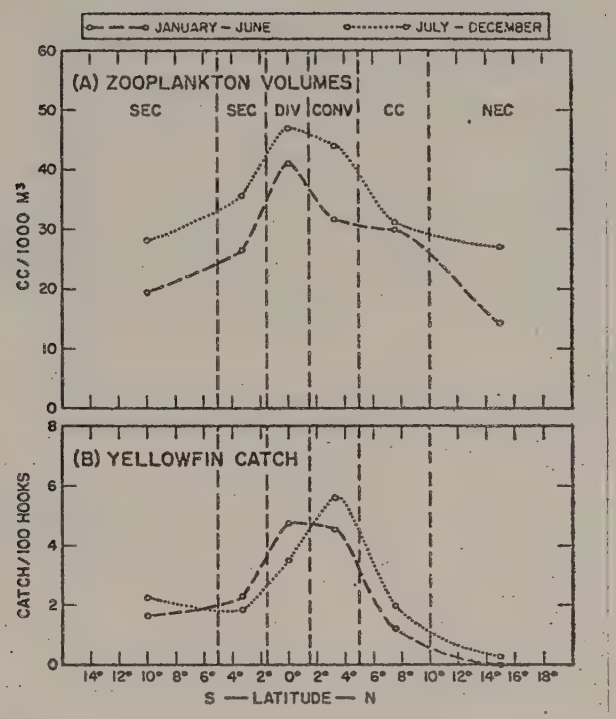


Figure 44.--Variation with the current system in (A) zooplankton volumes (adjusted) and (B) yellowfin tuna longline catch for the two 6-month periods, January-June, a period with northeast or light and variable winds, and July-December, a period of prevailing southeast trade winds (in the central equatorial Pacific Ocean) (from King and Hida 1957).

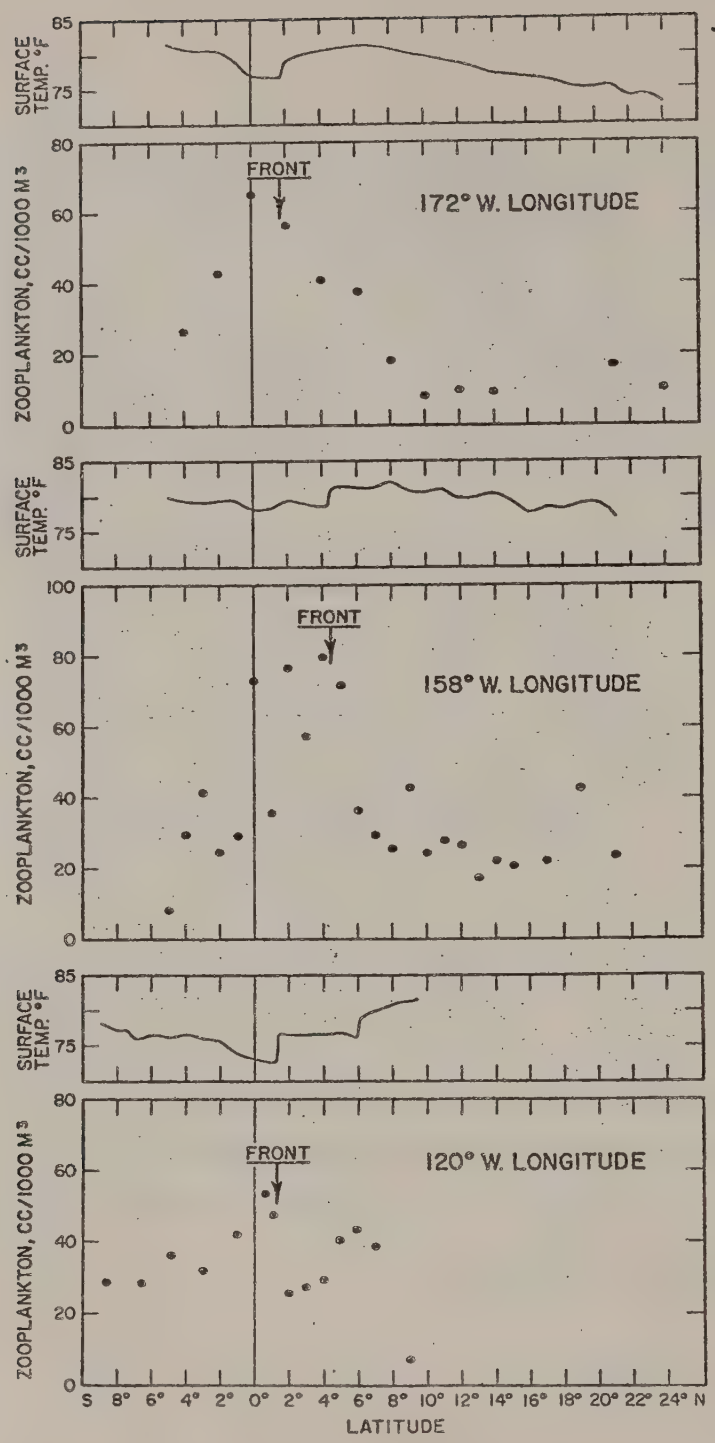


Figure 45.--Relation of an oceanographic front to the distribution of zooplankton (adjusted volumes) as demonstrated by three series of stations along long. 172°, 158°, and 120°W of Hugh M. Smith cruises 2, 5, and 18, respectively (from King and Hida 1957).

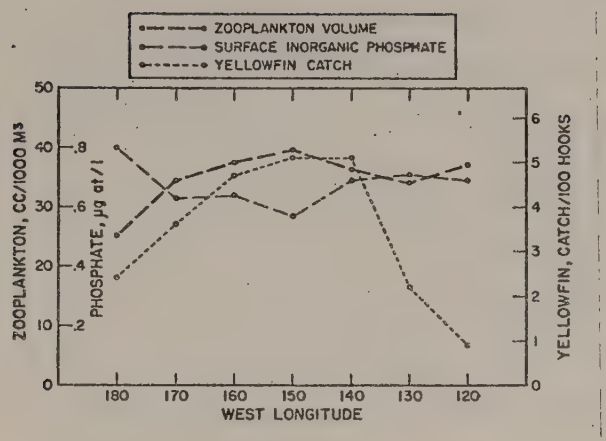


Figure 46.--Longitudinal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent, at about lat. 5°N to 5°S, with the data segregated by 10° intervals of longitude (from King and Hida 1957).

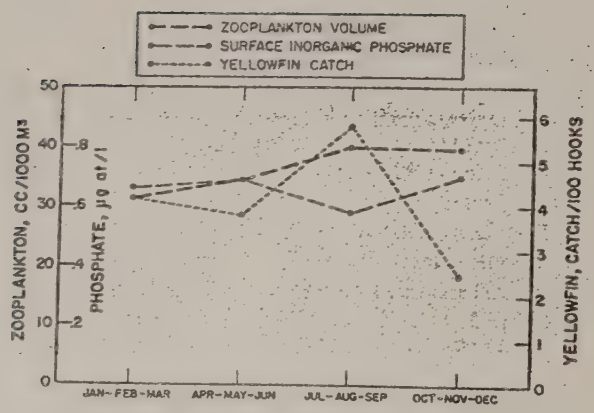
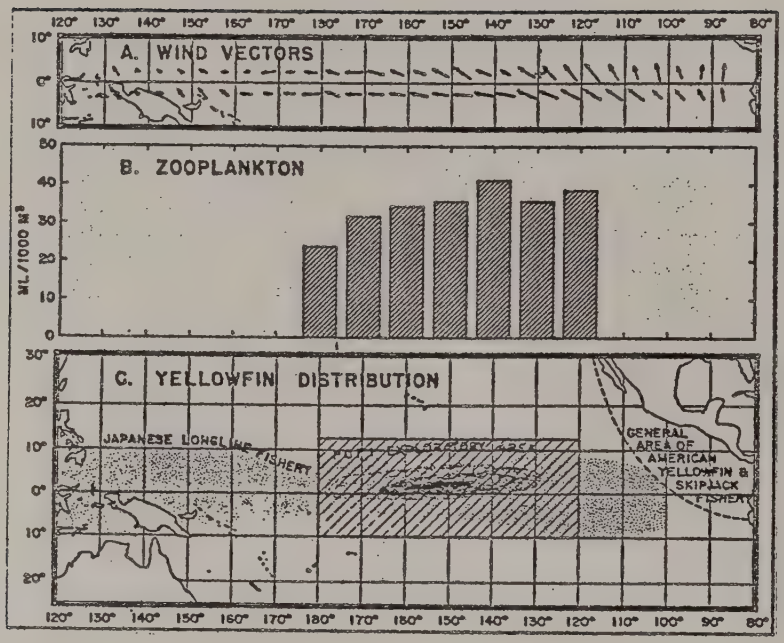


Figure 47.--Seasonal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent at about lat. 5°N to 5°S, with the data segregated into quarterly periods of 3 months each (from King and Hida 1957).

Figure 48.--Wind, plankton, and tuna distribution in the equatorial zone. A. Resultant wind vectors were computed as the weighted means of frequency and speed from the several compass points for 5° squares bordering the equator as published in the U.S. Hydrographic Office Pilot Chart for the North Pacific for August 1952; the arrows point in the direction of travel and their shafts are proportional to the weighted mean speed. B. Mean plankton volumes at several longitudes were computed as the mean of all hauls taken between lat. 5°S and 10°N at or near the given longitude. C. Distribution of yellowfin tuna in the mid-Pacific equatorial region is estimated from longline catches. The light stippling in the POFI area represents less than three yellowfin tuna per hundred hooks, the heaviest represents more than nine per hundred hooks, and the intermediate stippling represents intermediate catching rates. For orientation as to location and area, the extensive band of light stippling represents the area of the Japanese prewar longline fishery; the dashed outline shows the area of the American west coast live bait and purse seine fishery for yellowfin tuna and skipjack tuna. Since preparation of the above chart, a line of fishing stations along long. 110°W has proved the continuity of the band of yellowfin tuna across the "unexplored area" (from Sette 1955).


A. WIND VECTORS
B. ZOOPLANKTON
ML./1000 M³
C. YELLOWFIN DISTRIBUTION
JAPANESE LONGLINE FISHERY
GENERAL AREA OF AMERICAN YELLOWFIN & SKIPJACK FISHERY

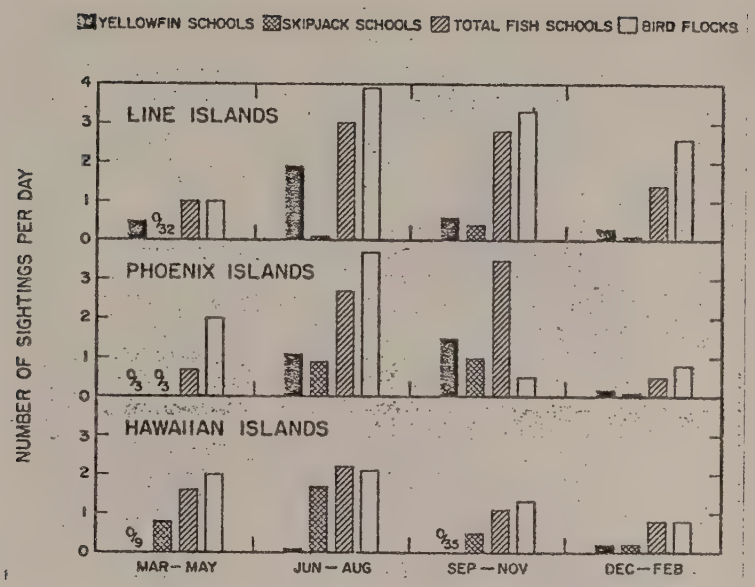


Figure 49.--Seasonal distribution of tuna school sightings in the Line, Phoenix, and Hawaiian Islands. Total fish schools per day include unidentified schools as well as yellowfin tuna and skipjack tuna. The numbers, such as 0/32, indicate that no schools were seen in 32 days of scouting (from Murphy and Ikehara 1955).

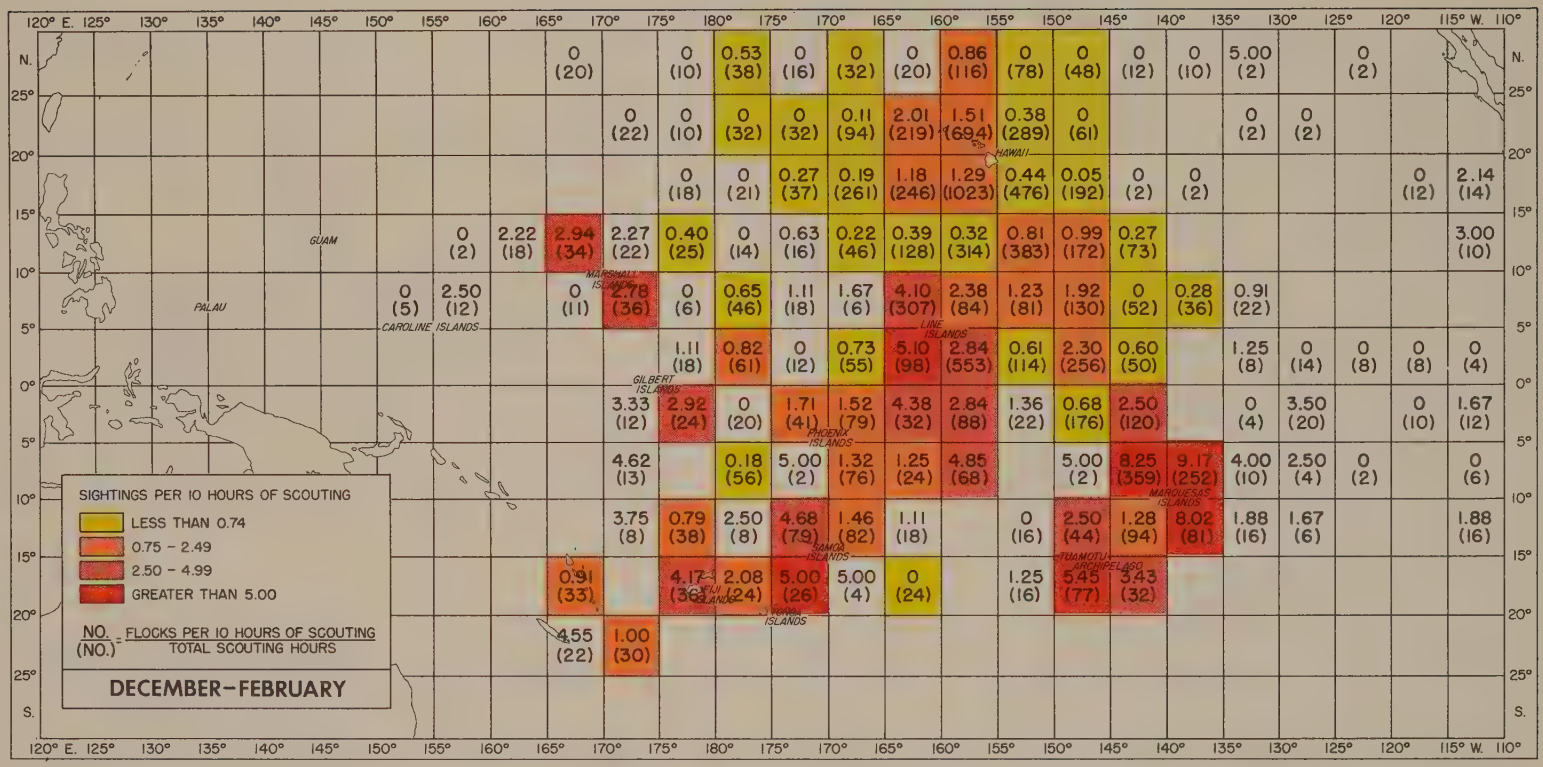


Figure 50a.--Bird flock sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

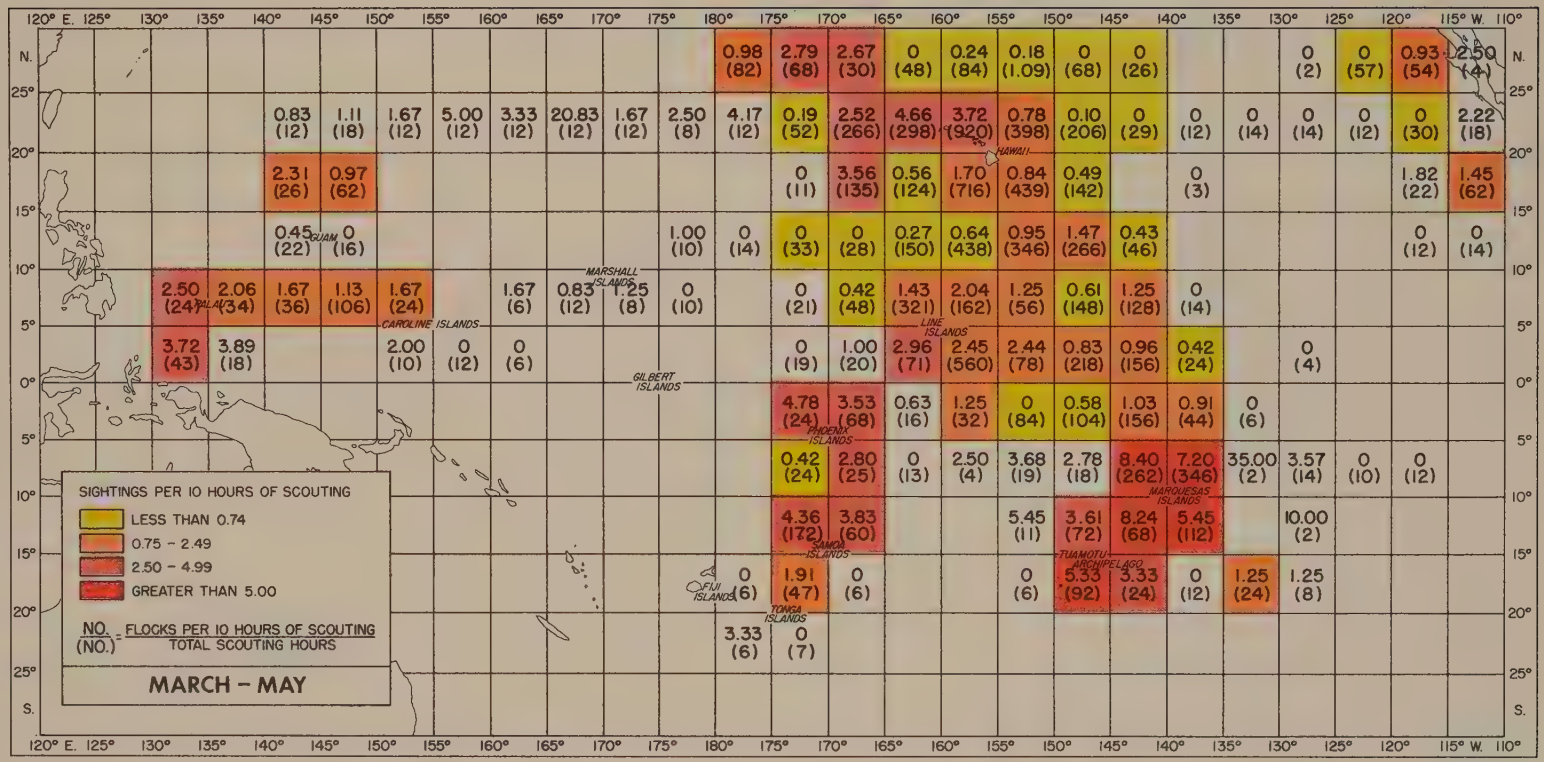


Figure 50b.--Bird flock sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

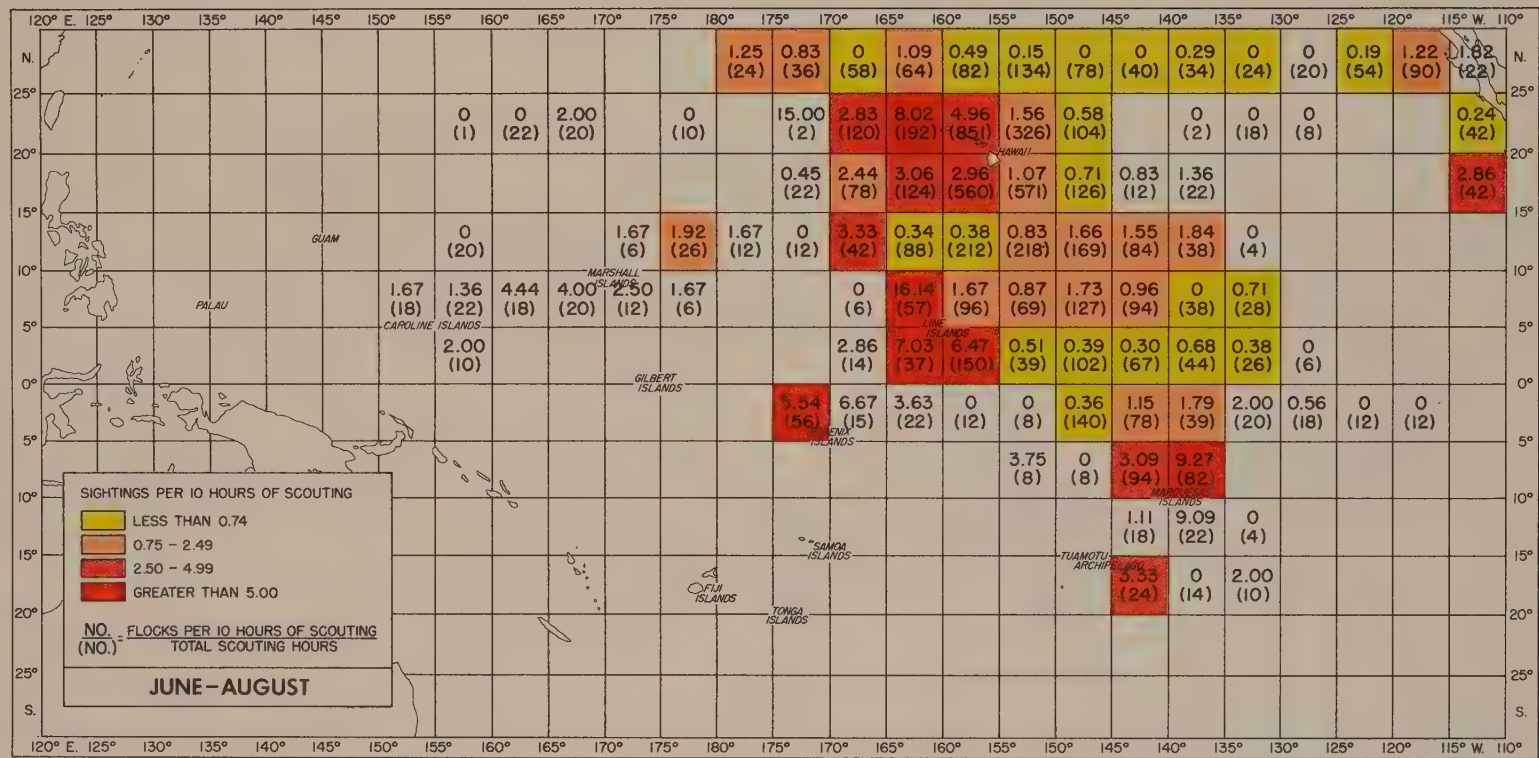


Figure 50c.--Bird flock sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

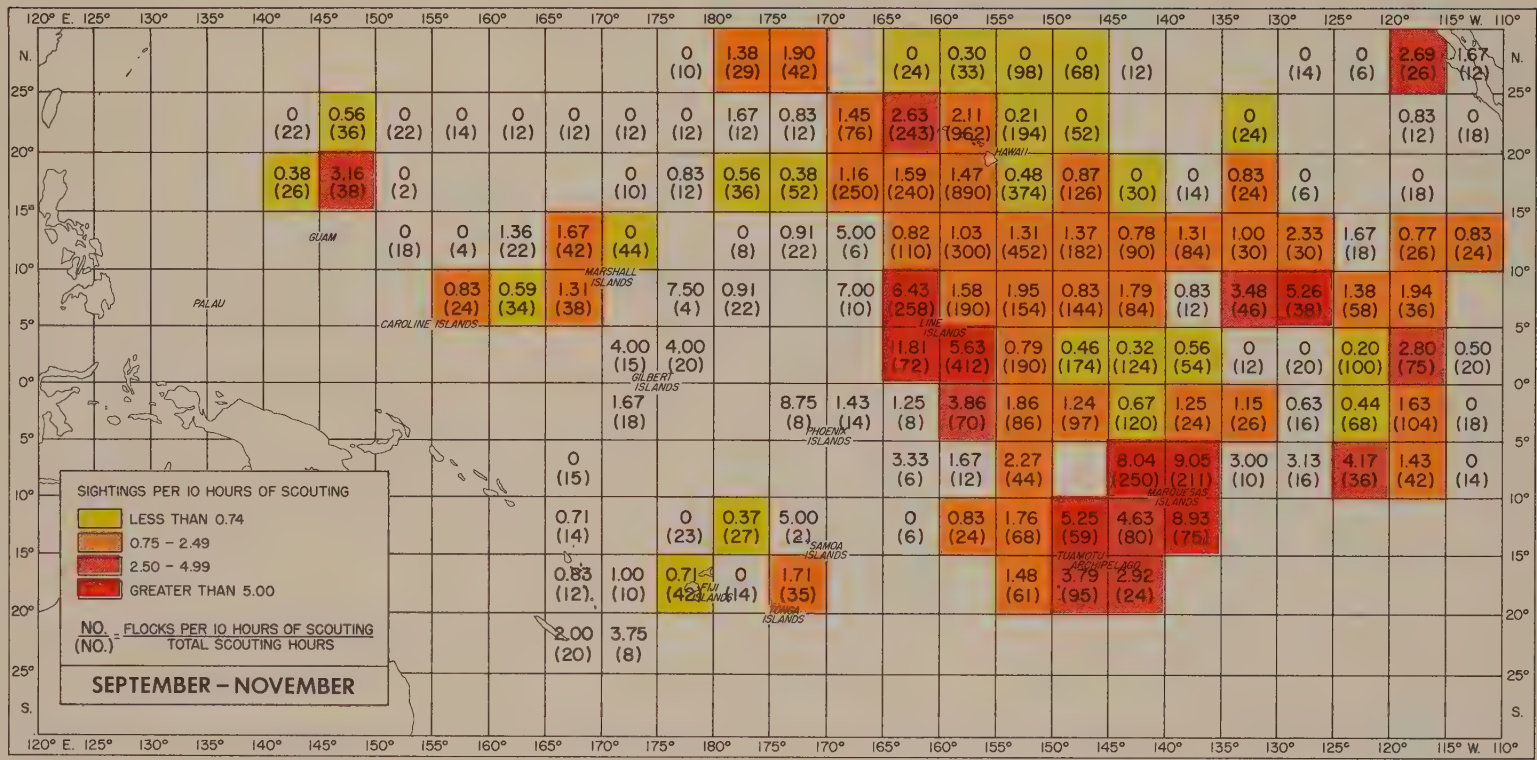


Figure 50d.--Bird flock sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

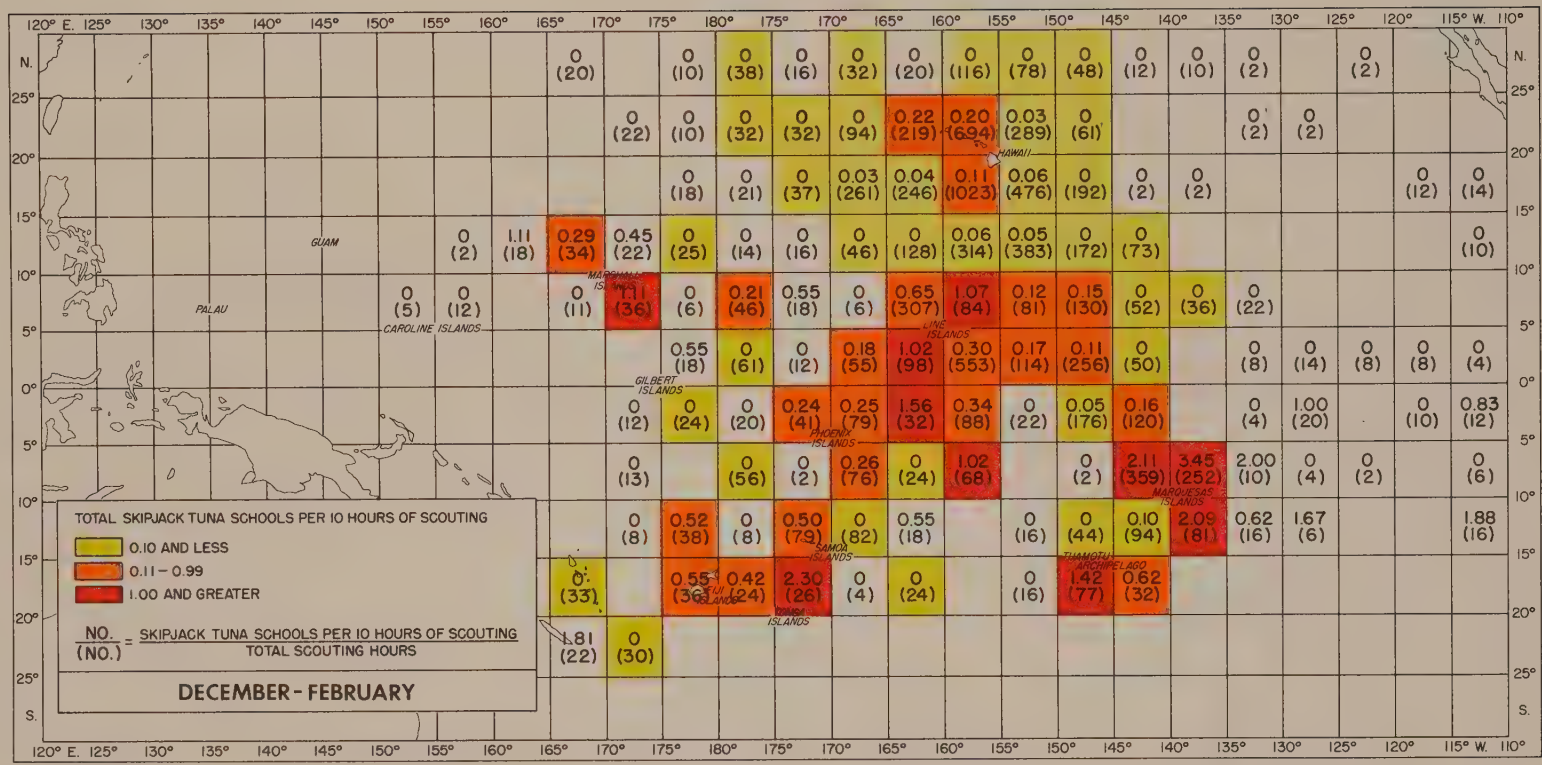


Figure 50e.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

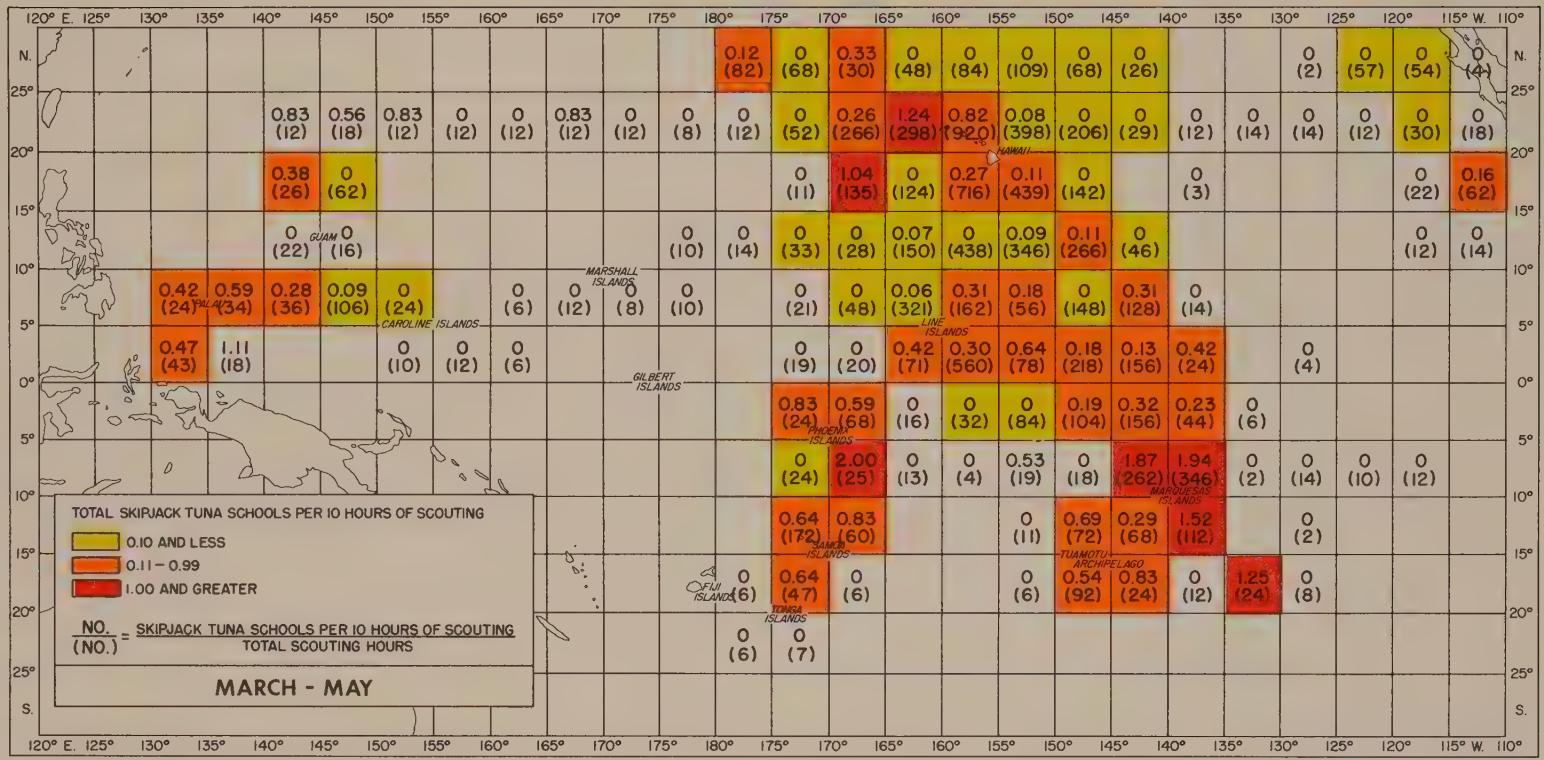


Figure 50f.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

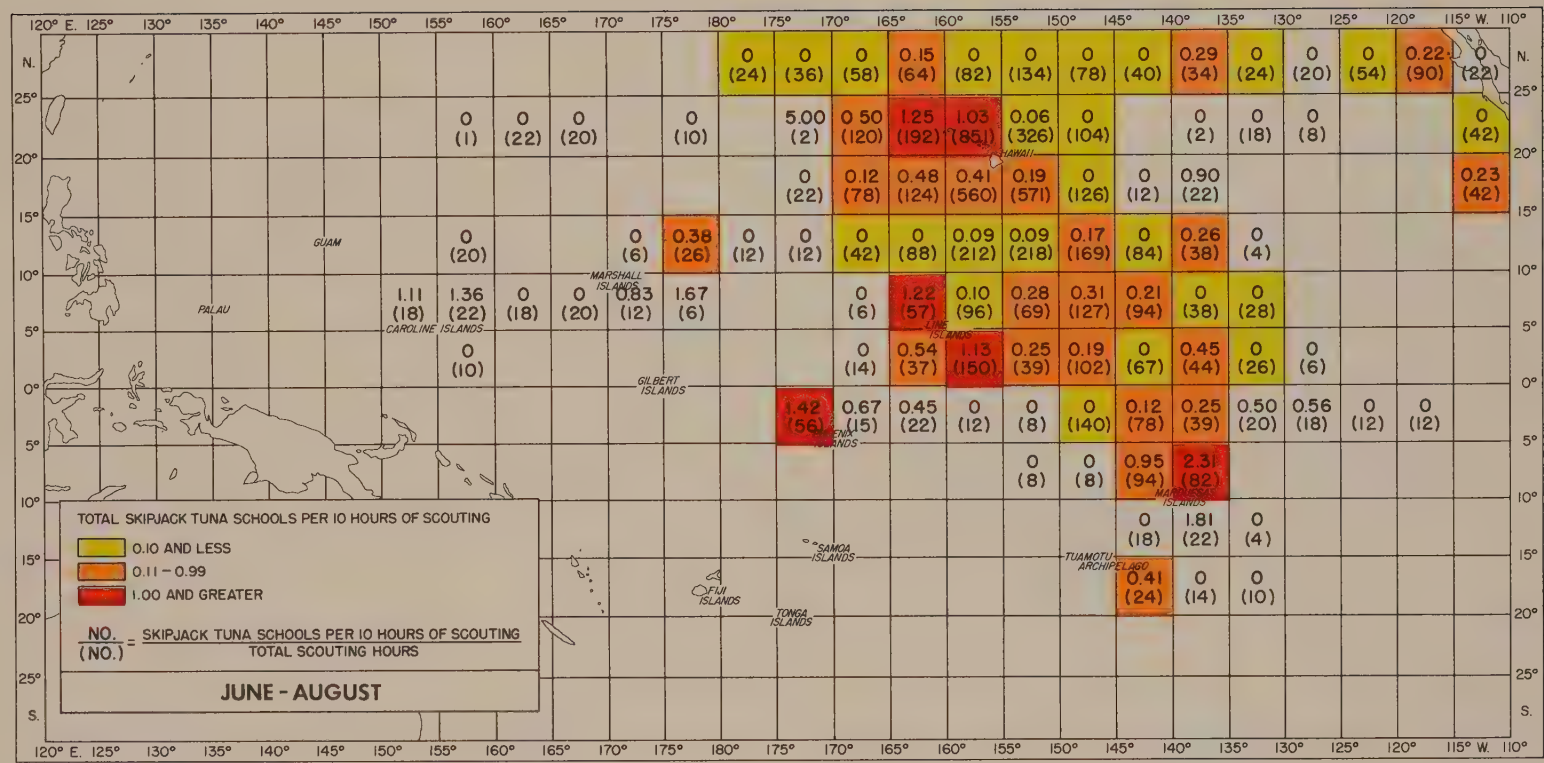


Figure 50g.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

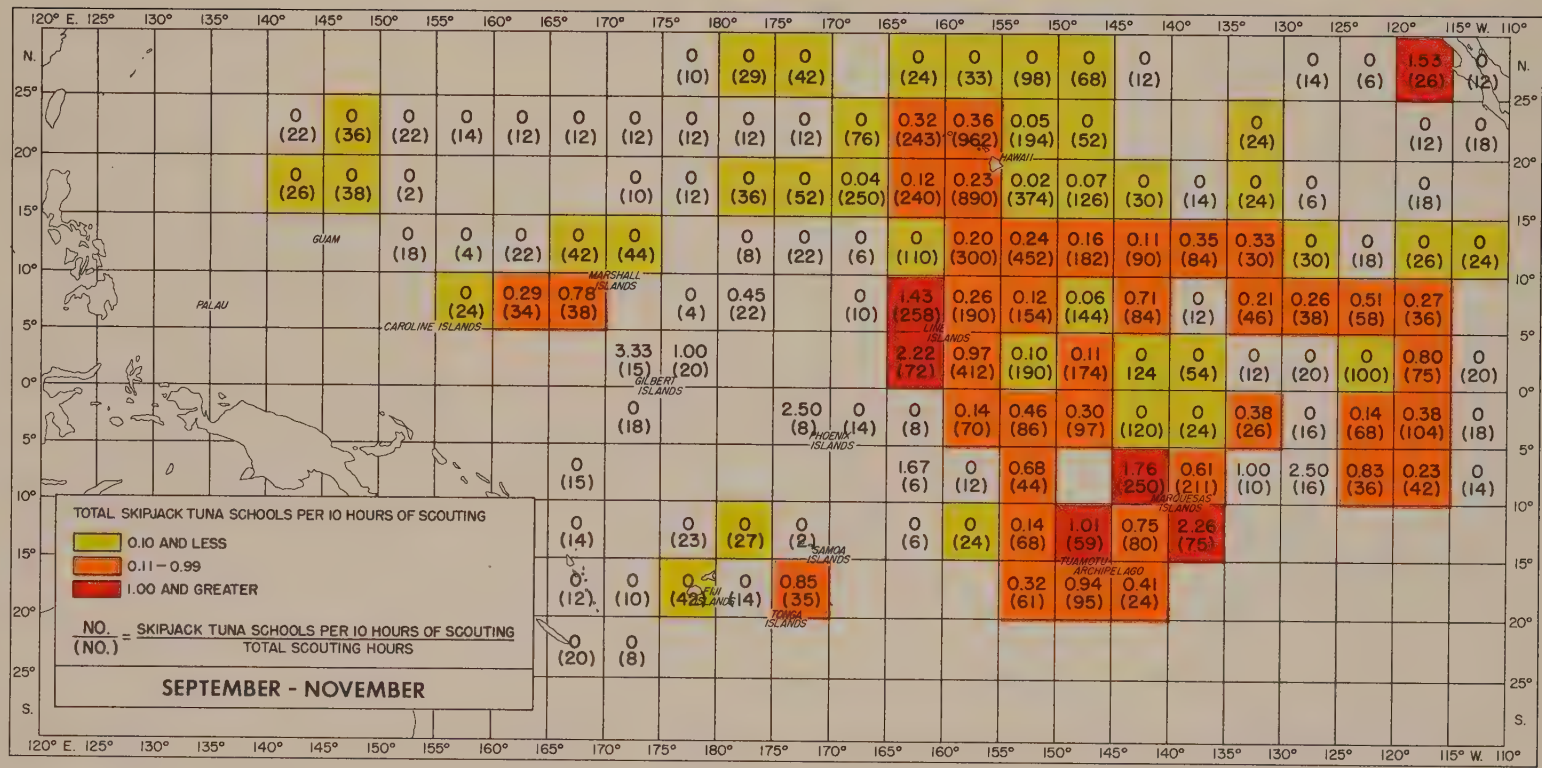


Figure 50h.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

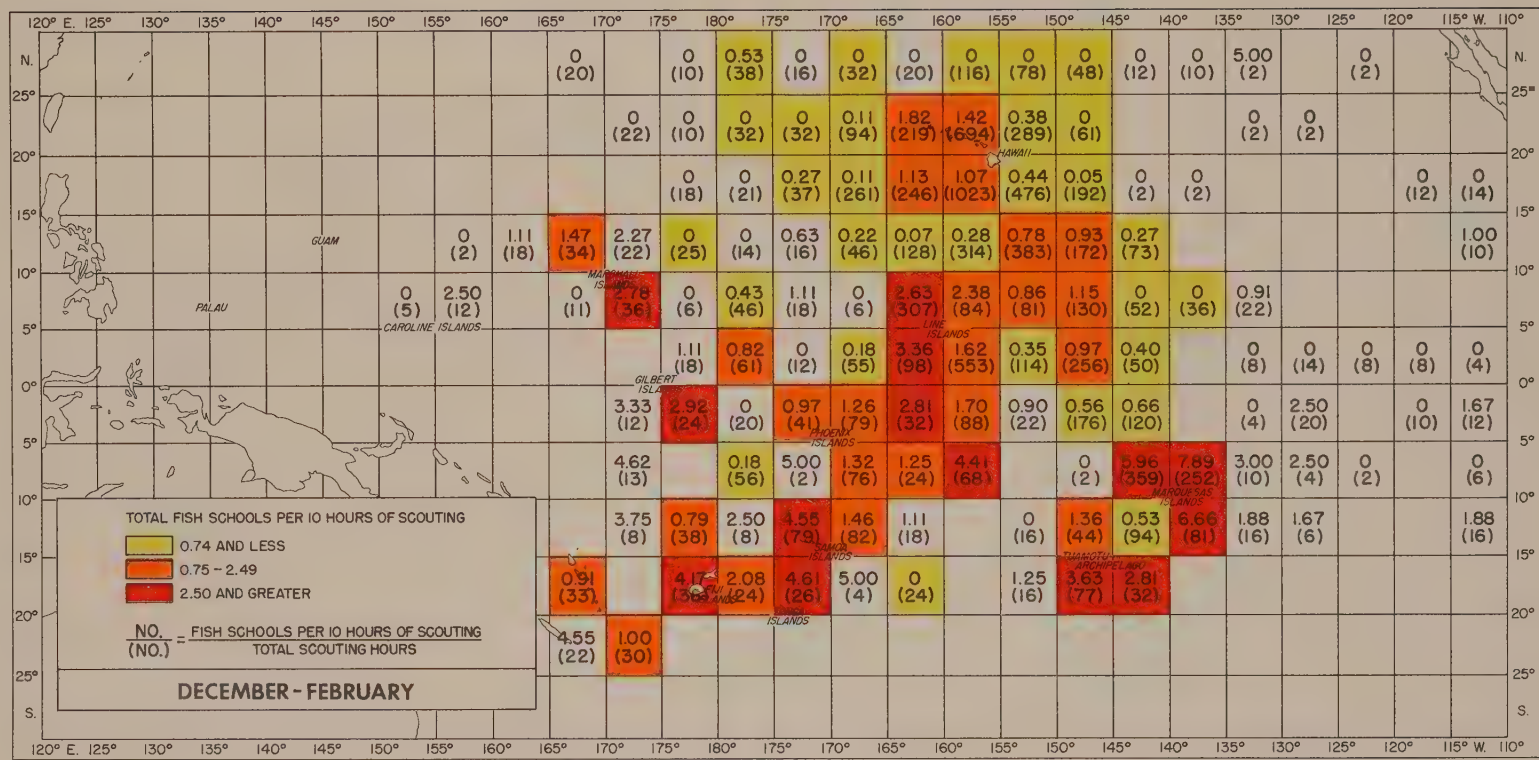


Figure 50i.--Total school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

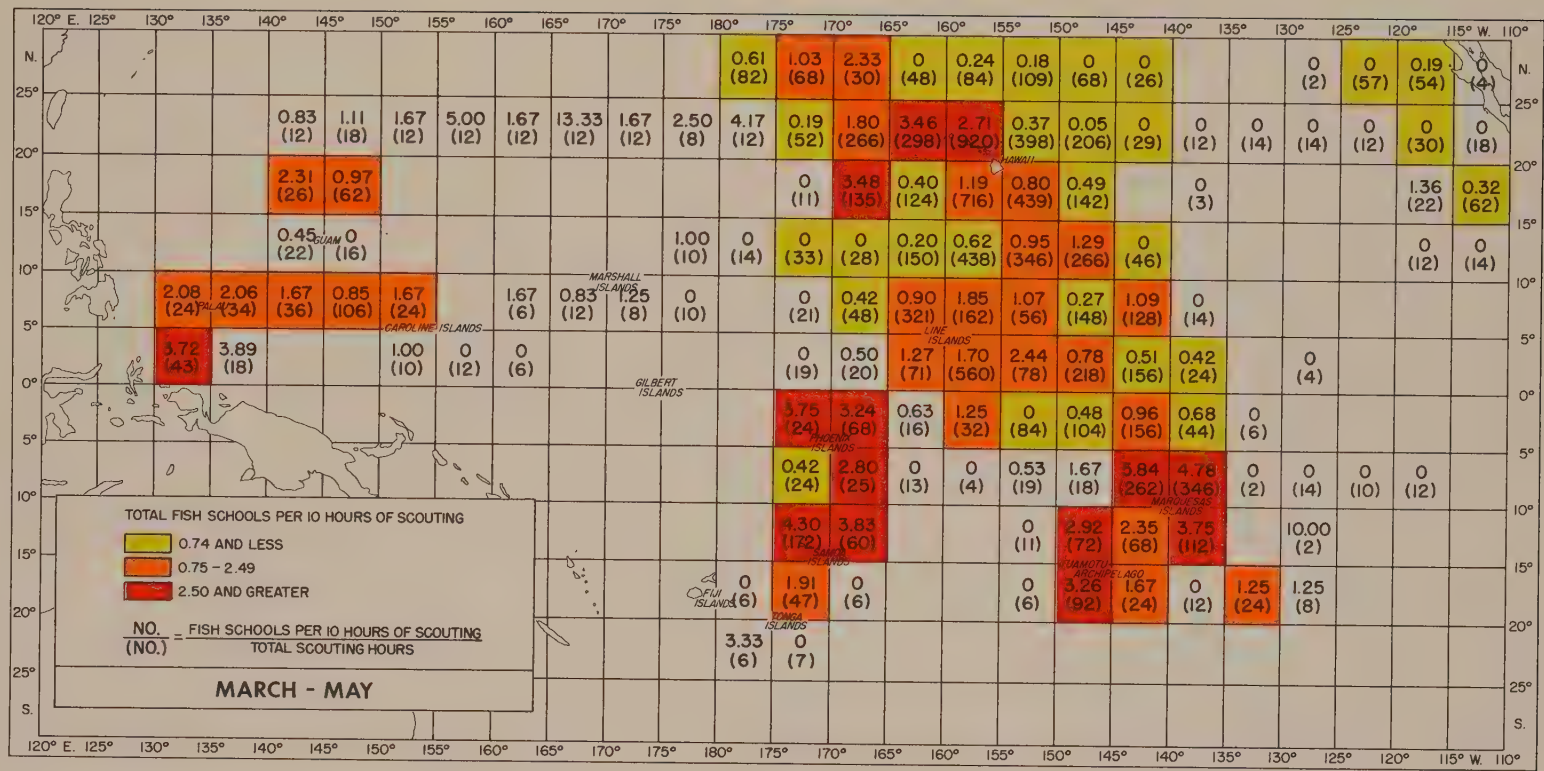


Figure 50j.--Total school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

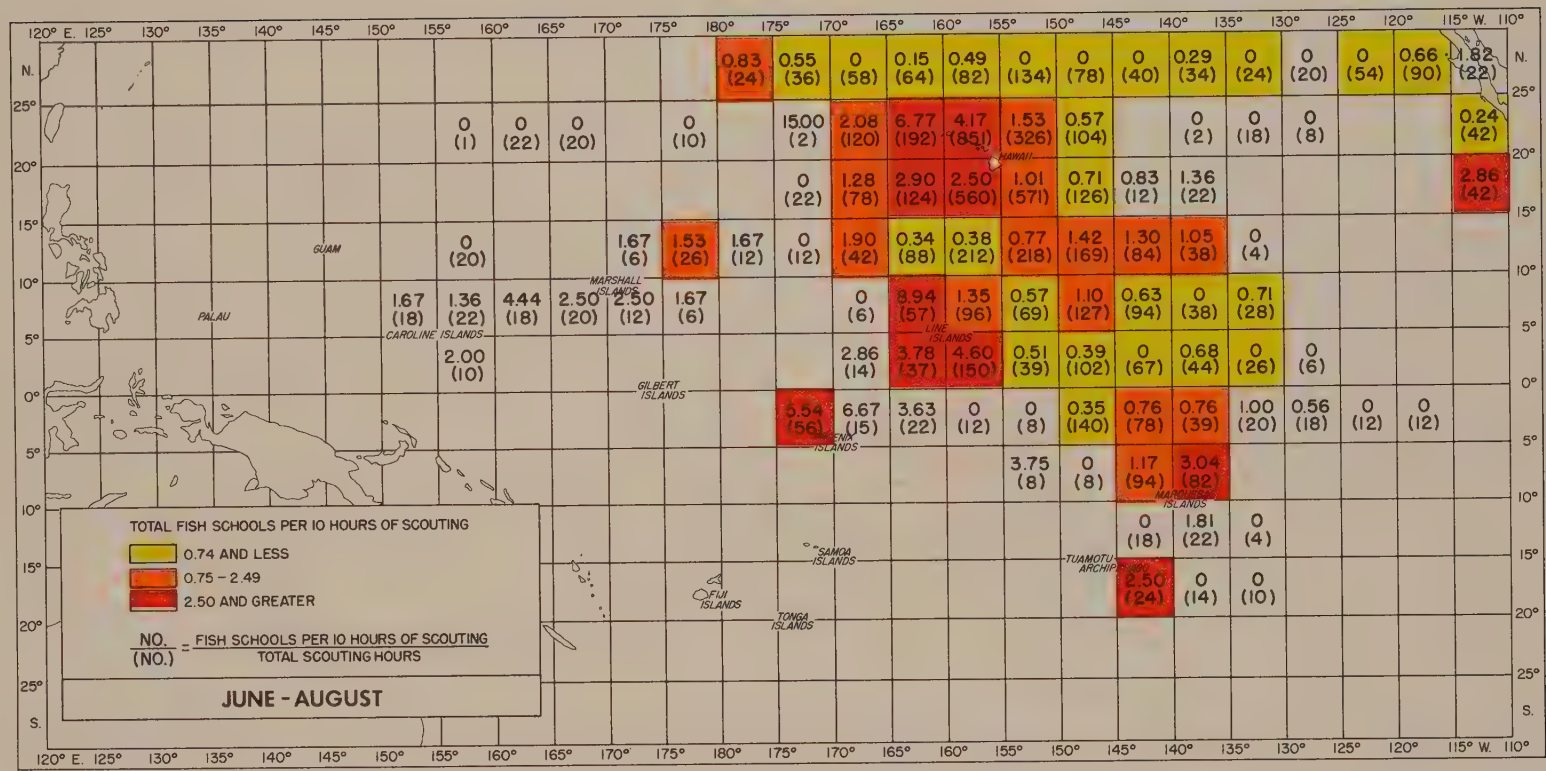


Figure 50k.--Total school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

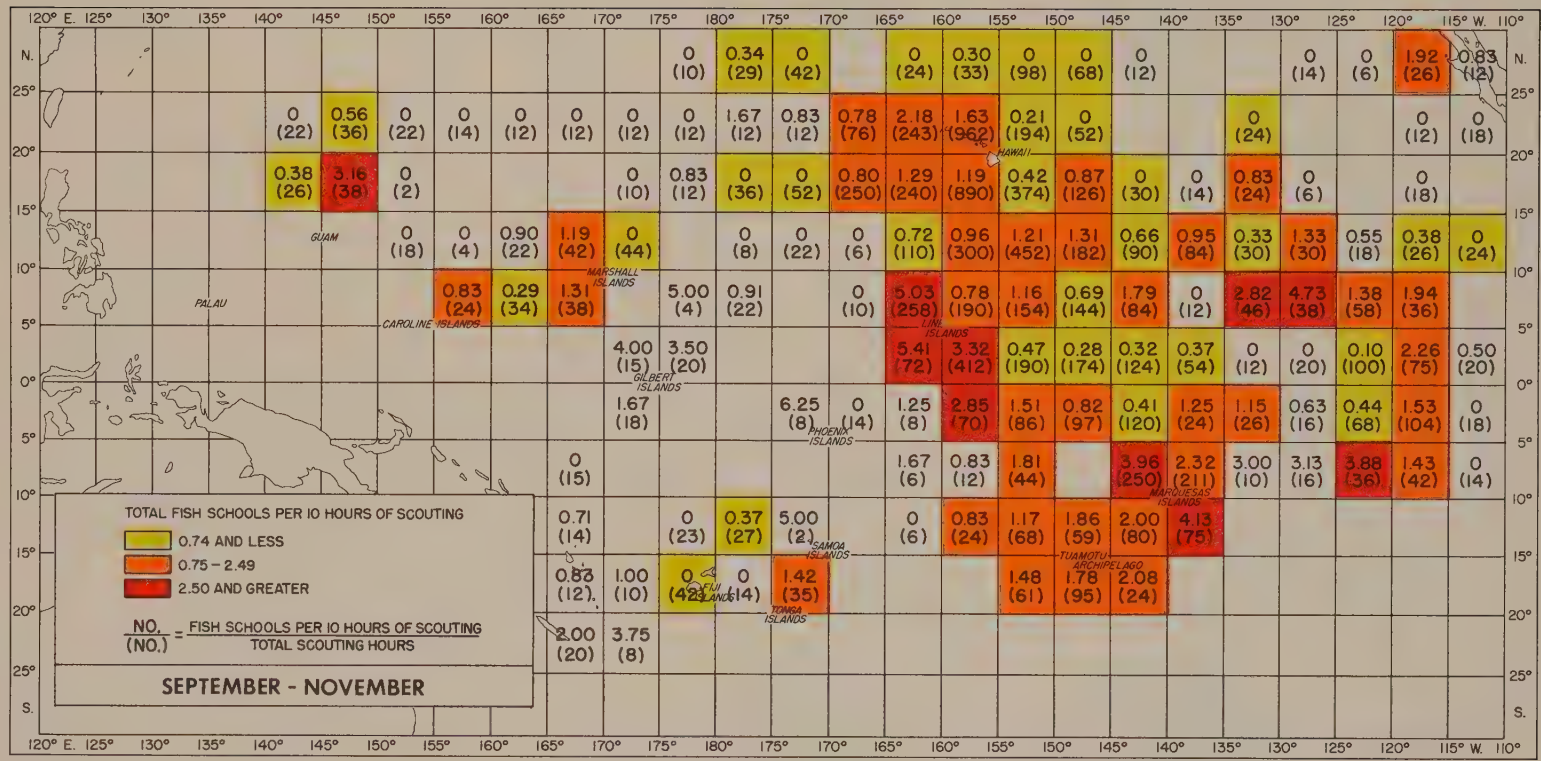


Figure 50ℓ.--Total school sightings by National Marine Fisheries Service vessels, September-November 1952-72 (from Naughton, see footnote 5).

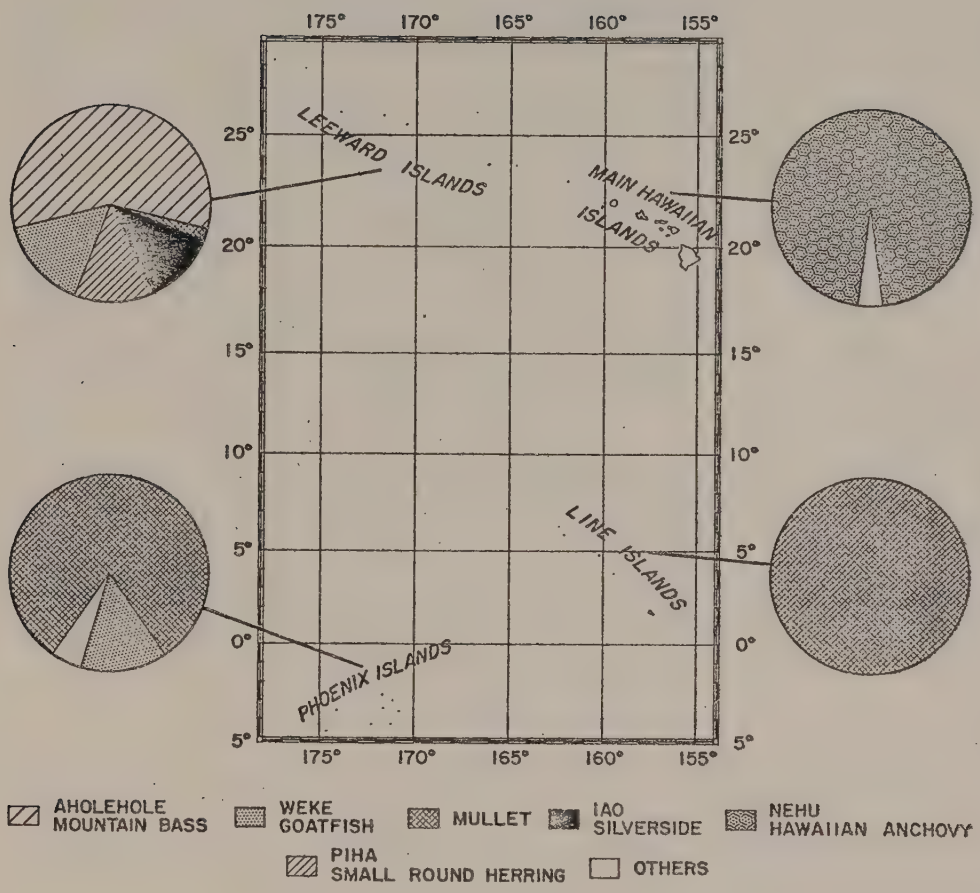


Figure 51.--Bait resources in the central Pacific islands (from Sette and staff 1954).

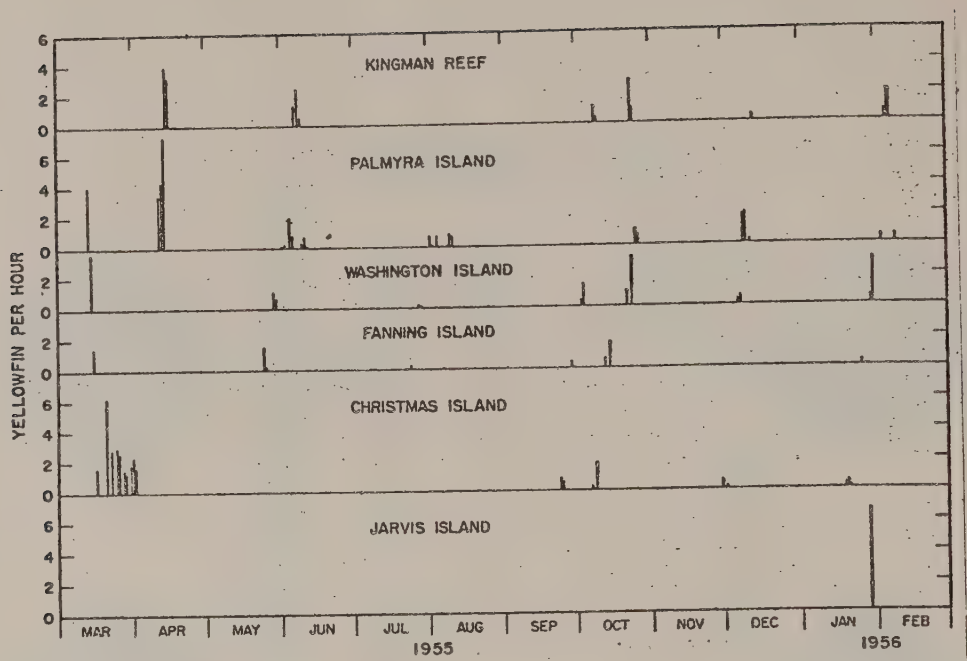


Figure 52.--Yellowfin tuna troll catch rates in the Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

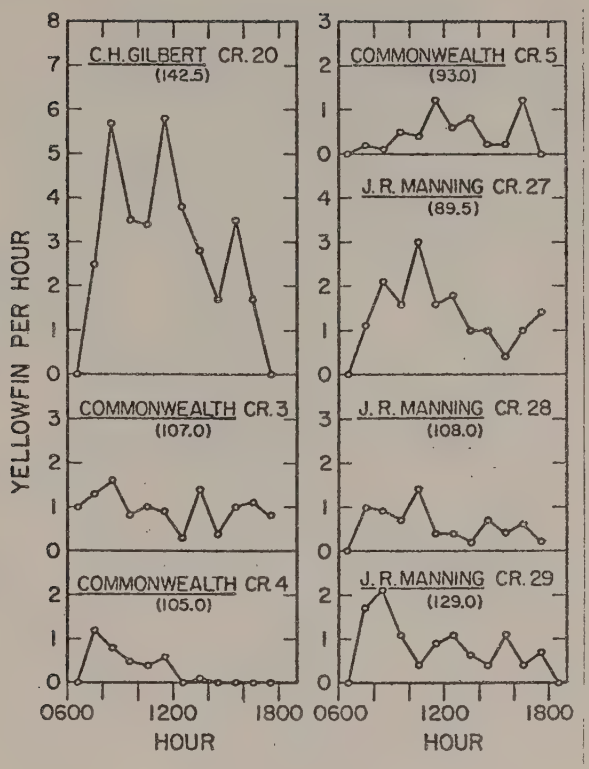


Figure 53.--Yellowfin tuna troll catch rates in the Line Islands 1955-56 arranged by time of day, (data on total number of hours trolled given in parentheses) (from Iversen and Yoshida 1957).

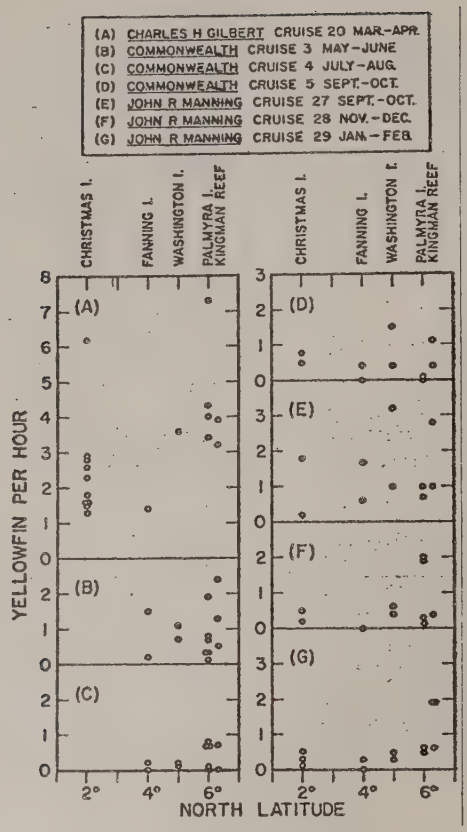


Figure 54.--Relationship of yellowfin tuna troll catch rates to areas, Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

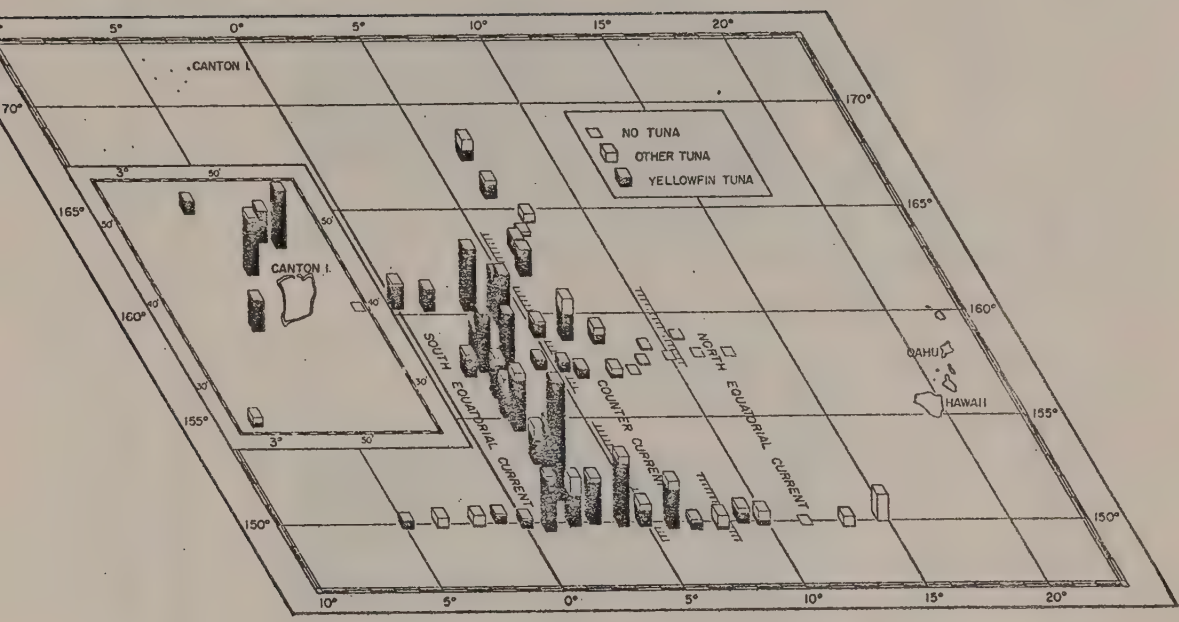


Figure 55.--Catches of tuna by Hugh M. Smith cruises 5, 7, and 11, 1950-51. The bar graphs represent tuna catch rates, yellowfin tuna shown in black, other tunas in white (from Murphy and Shomura 1953a).

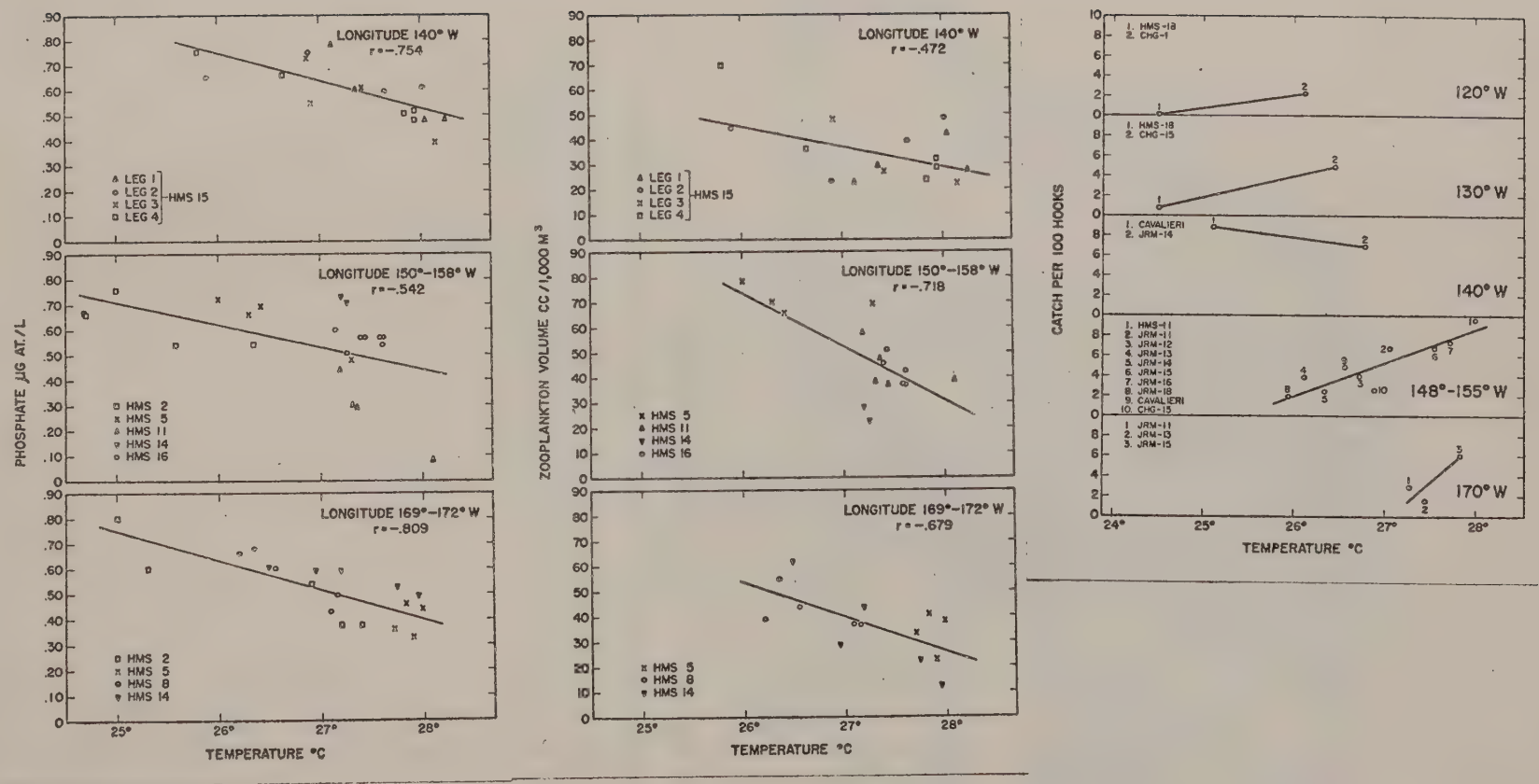


Figure 56.--Relationship between surface temperature and phosphate, zooplankton volume, and yellowfin tuna catch at several longitudes for the zone lying between lat. 1° and 5°N (from Murphy and Shomura 1972).

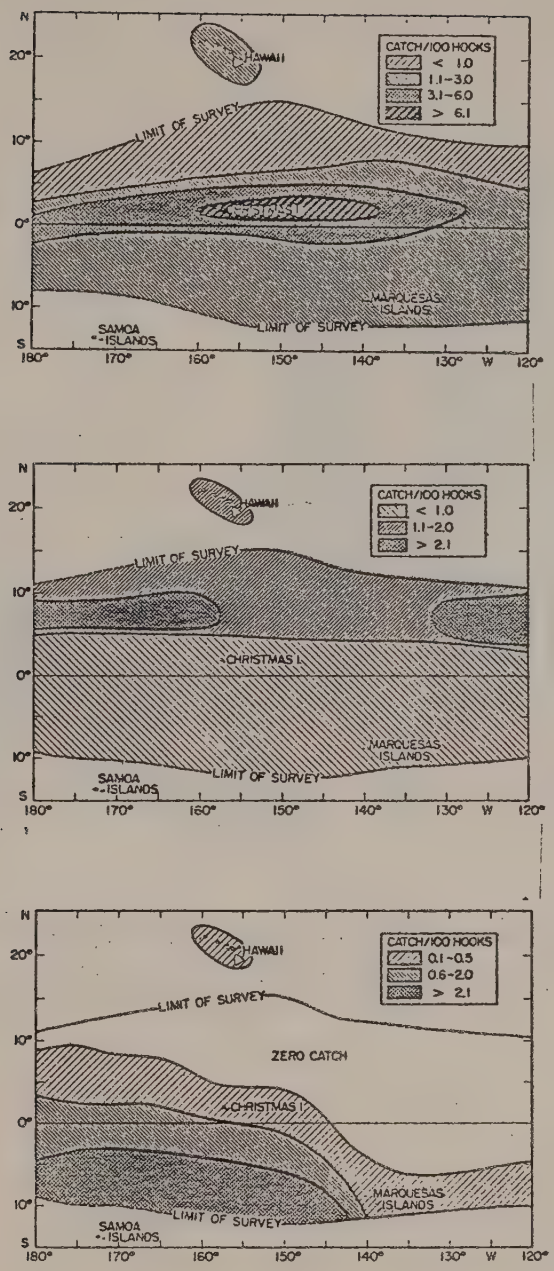


Figure 57.--The distribution of deep-swimming yellowfin tuna (top), bigeye tuna (middle), and albacore (bottom) in the central equatorial Pacific Ocean. The isograms are in units of number of fish caught per 100 hooks (from Murphy and Shomura 1972).

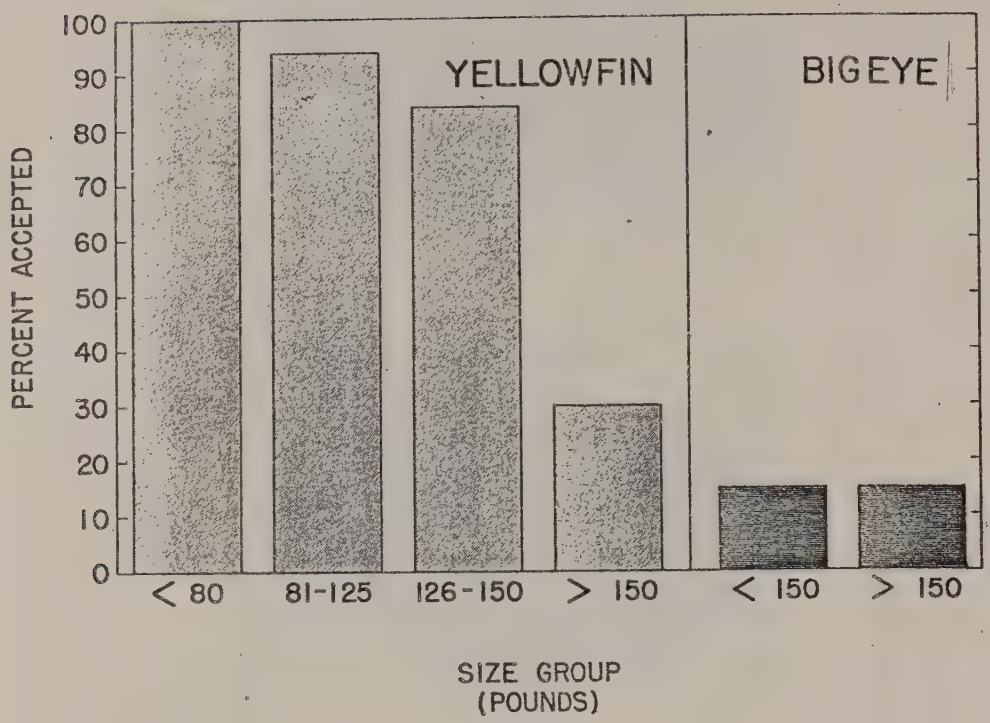


Figure 58.--Percentage of Cavalieri's longline-caught tuna acceptable for canning (from Sette and staff 1954).

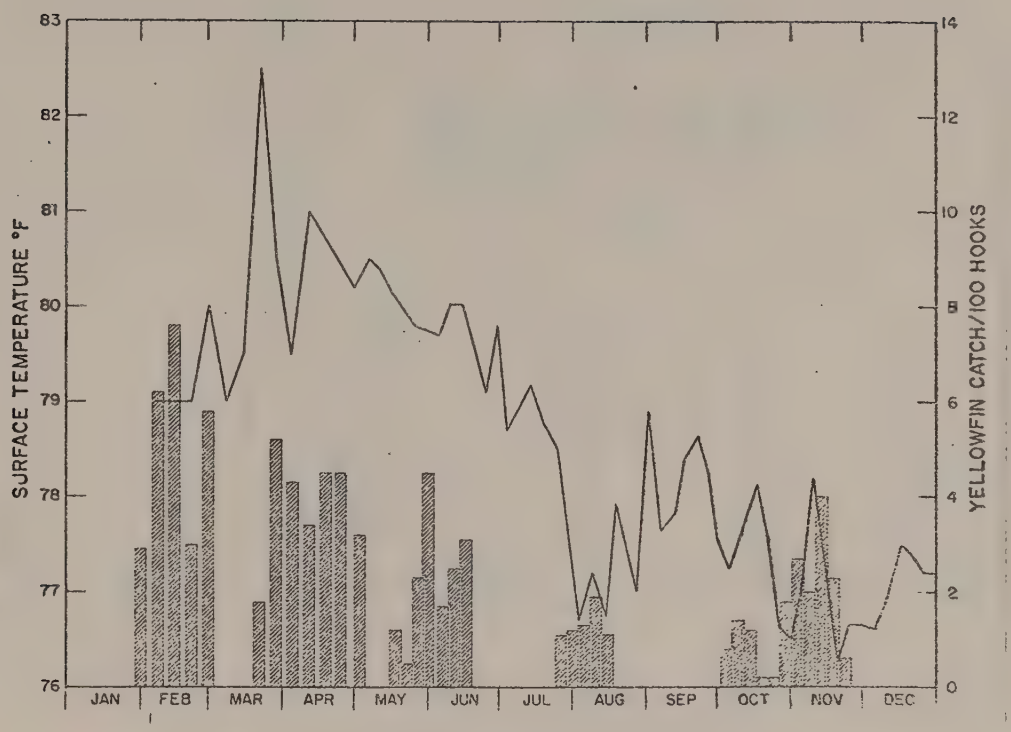


Figure 59.--Surface temperatures at Christmas Island and Line Islands yellowfin tuna catches during 1954 by 5-day periods (from Iversen and Yoshida 1956).

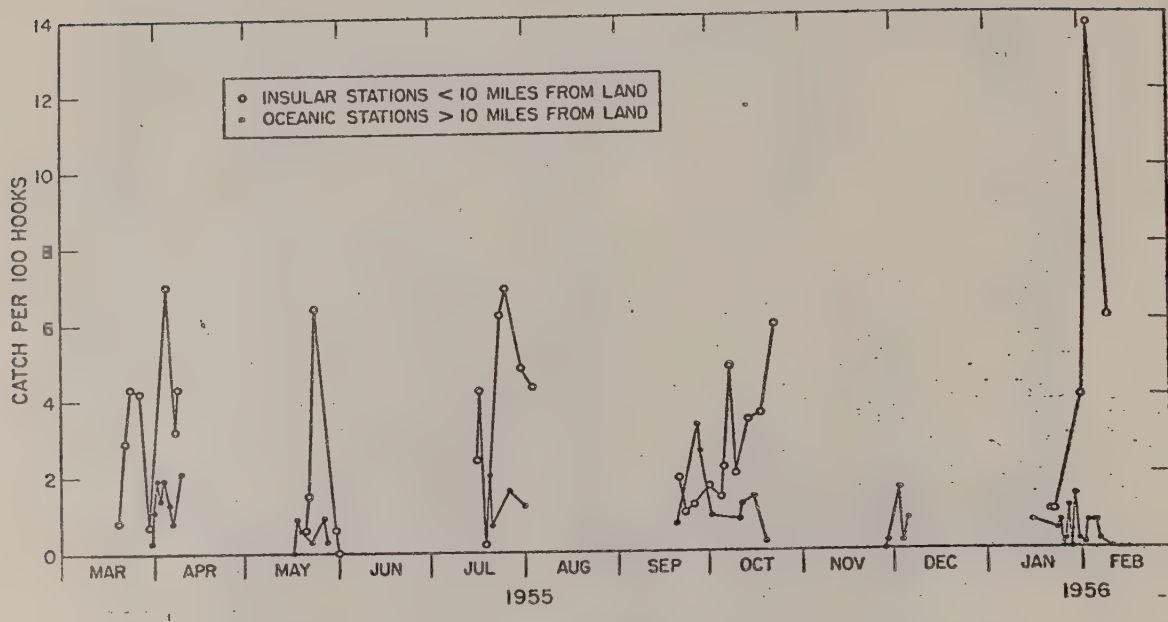


Figure 60.--Daily yellowfin tuna longline catch rates in the Line Islands, 1955-56 (from Iversen and Yoshida 1957).

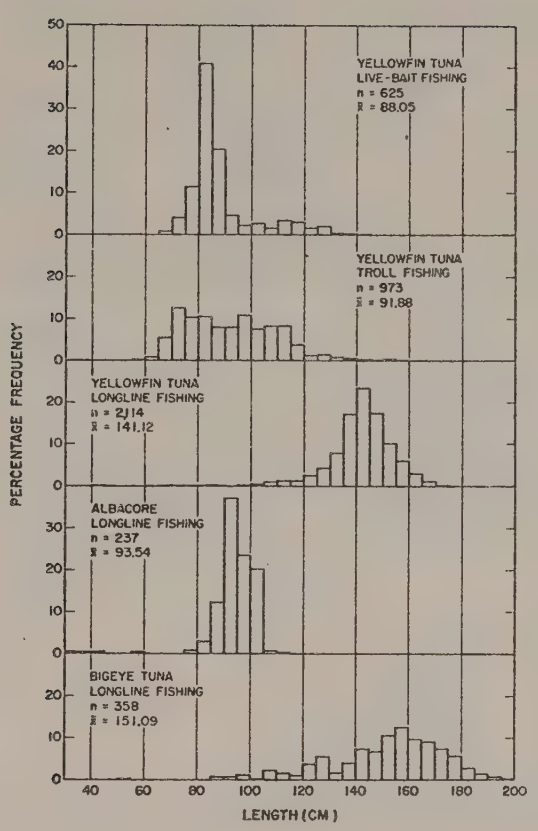


Figure 61.--Length frequencies (fork lengths) of the principal tuna species taken in the central equatorial Pacific by type of gear (from Murphy and Shomura 1972).

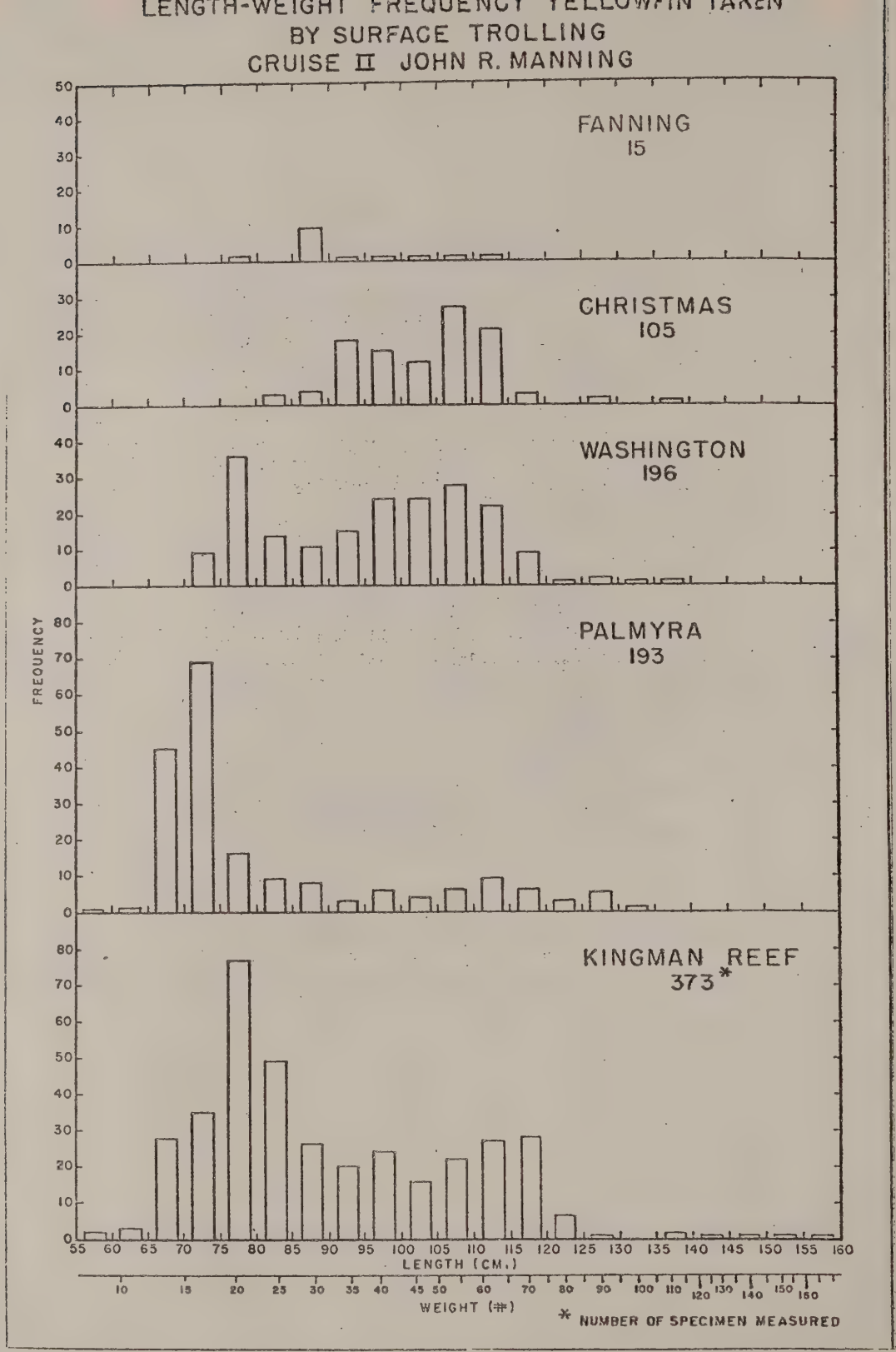


Figure 62.--Length-weight frequency distribution of yellowfin tuna caught by surface trolling in the Line Islands, 1950 (from Bates 1950)

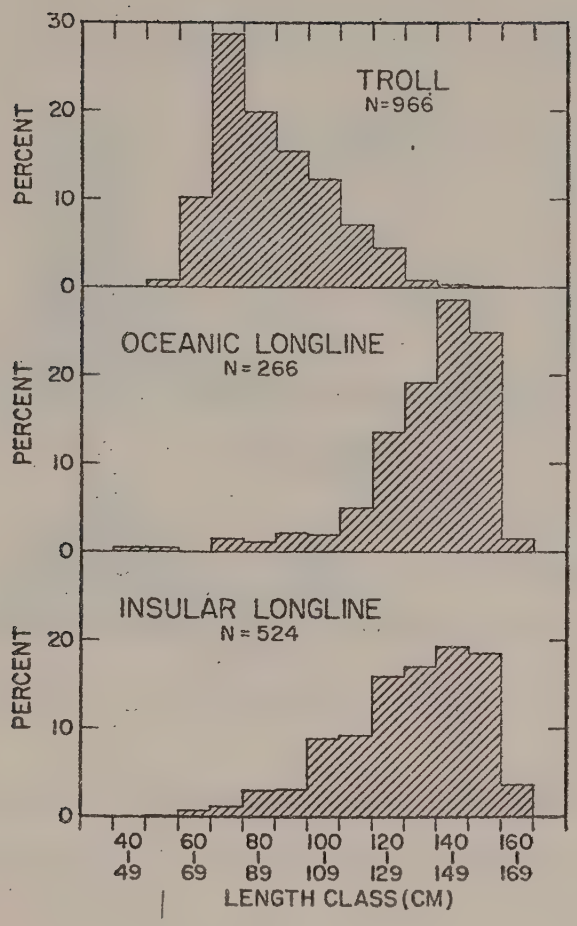


Figure 63.--Length-frequency distributions of oceanic and insular yellowfin tuna caught by longlining and trolling, January 1955 to February 1956 (from Iversen and Yoshida 1957).

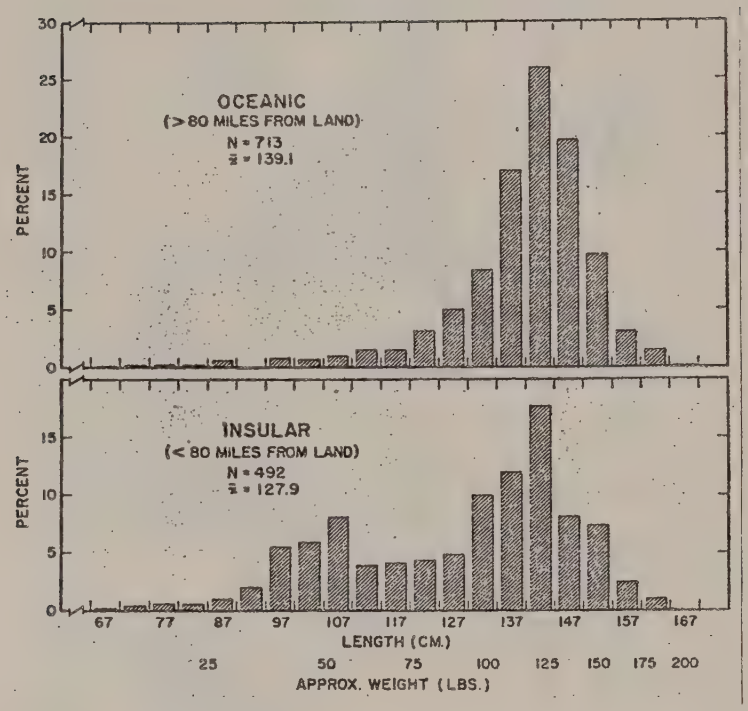


Figure 64.--Yellowfin tuna size distribution with distance from land, January-December 1953 (from Shomura and Murphy 1955).

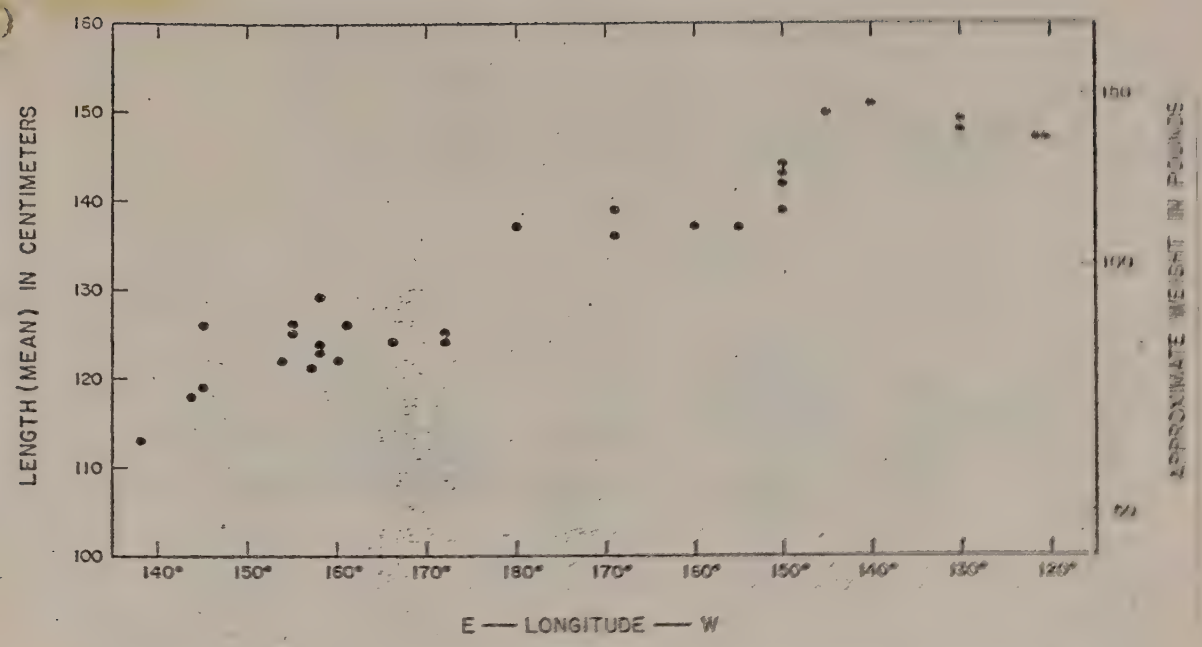


Figure 65.--Mean lengths of samples of longline-caught yellowfin tuna plotted against longitude of capture, August-November 1951 (from Murphy and Shomura 1955).

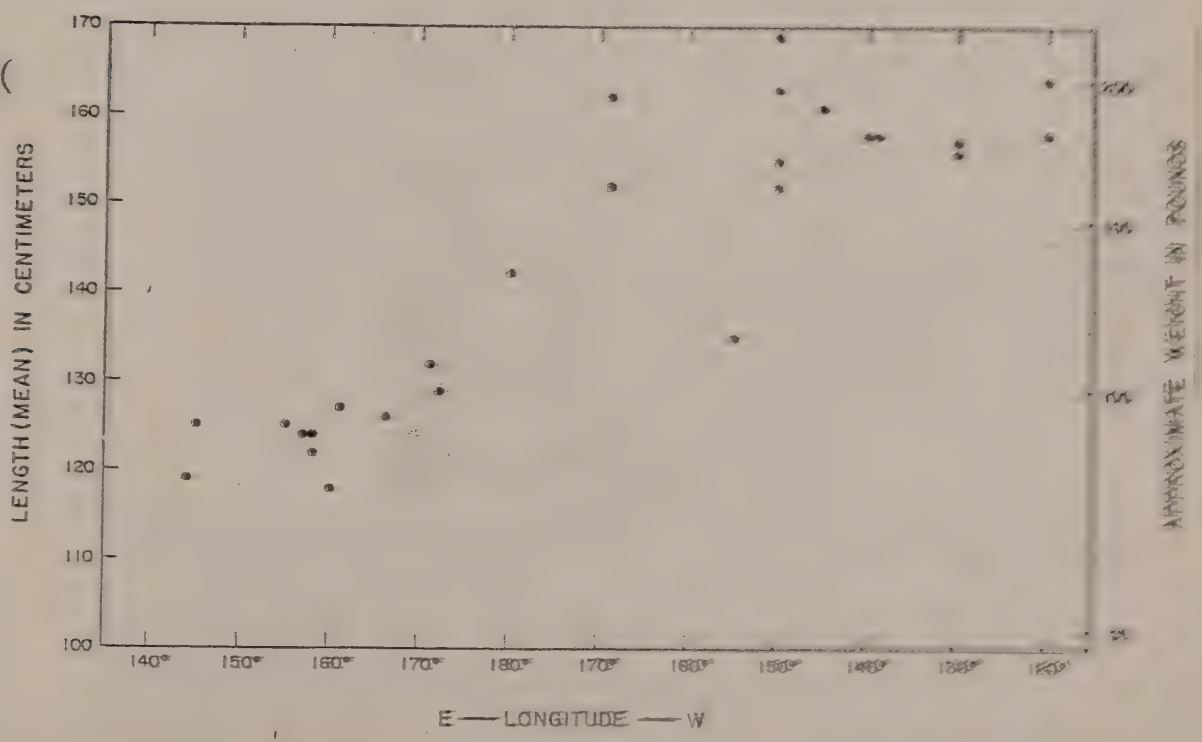


Figure 66.--Mean lengths of samples of longline-caught albacore tuna plotted against the longitude of capture, August-November 1951 (from Murphy and Shomura 1955).

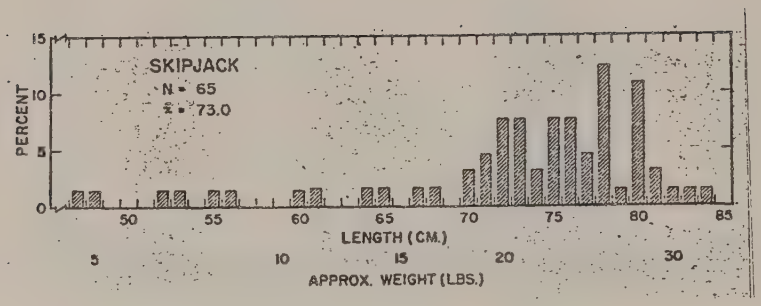


Figure 67.--Size distribution of skipjack tuna taken by longline in the central equatorial Pacific, 1953 (from Shomura and Murphy 1955).

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southwest Fisheries Center
Honolulu and La Jolla Laboratories
P. O. Box 3830
Honolulu, Hawaii 96812

Date: March 11, 1976 Reply to Attn. of:

To: Richard S. Shomura, Director, Honolulu Laboratory F142

From: Tamio Otsu, Chief, Tuna Assessment and Development Investigations

Subject: Trip report, trip to Japan, January 30-February 20, 1976

My itinerary on this trip to Japan was as follows:

January	30	- 1430, departed Honolulu via NW 009.
	31	- 1830, arrived Tokyo.
February	1-9	- In Shimizu, Shizuoka Prefecture. Attended Japanese Tuna Research Conference, visited staff members of Far Seas Fisheries Research Laboratory, and Tokai University Faculty of Marine Science and Technology.
	10	- In Tokyo. Visited the Japan Marine Fishery Resource Research Center (JAMARC), and the American Embassy.
	11-12	- In Sendai. Visited the Tohoku Regional Fisheries Research Laboratory in Shiogama City.
	13-19	- In Tokyo. Visited staff members of various government and industry offices including Overseas Fishery Cooperation Foundation, Bumble Bee Seafoods Co Universal Marine Consultant Co., Japan Fisheries Agency, Iwatani & Co., Ltd., Japan Marine Products Photo Materials Association, Sanyo Hydrographic Survey Co., and Asuka Manufacturing Co., Ltd.
	20	- 2130, departed Tokyo via NW 010. - 0930, arrived Honolulu.

This trip report is arranged by subject matter. The following subjects are covered:

A. The Japanese tuna fishery in continuing depression

B. The tuna longline fishery of Taiwan and Korea

C. Japanese southern water skipjack tuna fishery, February-December 1975

D. Tuna purse seining

E. Skipjack tuna fishery survey in Micronesia

F. Bluefin tuna rearing

G. The bluefin tuna fishery in Hokkaido

H. Antarctic krill

I. List of persons contacted during trip.

A. THE JAPANESE TUNA FISHERY IN CONTINUING DEPRESSION

In last year's trip report, dated March 28, 1975, I reported that the Japanese tuna industry was facing a major depression as a result of 1) tripling of oil prices, 2) increased cost of fishing gear and provisions needed for extended fishing operations, 3) generally declining catch rates throughout the areas of operation, 4) depressed fish prices in Japan, and 5) virtual closing of the United States markets to Japanese exports of albacore, yellowfin, and skipjack tunas.

The situation has not changed. In spite of the fact that there have been increases in fish prices, both domestically and abroad (particularly in export prices for albacore), and a gradual re-opening of the U.S. market, other factors tend to keep the industry in a continuing dilemma. Although albacore prices in the U.S. have increased considerably to $1,150-$1,200 per short ton, CIF, and skipjack tuna prices to $750 per short ton, CIF, the Japanese industry officials consider these prices marginal. It is for this reason that the Japanese industry has undertaken a major promotional campaign to increase sales of canned tuna in the domestic market. The Japanese feel that the export market is too unstable, that in order to stabilize the industry, they must promote greater utilization of albacore and skipjack tuna at home. This effort has been paying off, since the domestic consumption of canned albacore has been increasing each year and has reached approximately 2 million cases (about 20,000 metric tons (MT)) at present, primarily of HAGOROMO's "Sea Chicken" brand.

One crisis after another

The Japanese tuna fishery has faced one crisis after another the past several years. These included the Bikini radioactivity crisis, the canned tuna "decomposition" problem, the dollar devaluation, the

---

Conversion rate used in this report: 300 yen to US$1.

mercury-in-tuna problem, and most recently, the "oil shock." Today the industry is attempting to counteract the prevailing depression in the tuna industry by taking certain positive steps to stabilize fish prices. It is purchasing fish (particularly albacore) directly from the vessels and holding it in freezers during periods of low prices; promoting increased domestic consumption of tunas that were formerly exported; restricting imports of tunas, particularly those fish delivered directly to Japanese ports by foreign vessels; securing government assistance in providing a fuel subsidy to tuna vessels; and reducing the number of vessels in the tuna fleet.

The Japanese tuna industry is primarily a conglomeration of small businesses. Most of the ship owners manage only one or two vessels. In 1975 there were 1,688 vessel owners operating a total of 2,670 longline and pole-and-line vessels. The average number of ships operated per owner was 1.6. This can be broken down further: 68.4% of the owners operated only one vessel; 18.1%, 2 vessels; 7.2%, 3 vessels; 3.7%, 4 vessels; and the remaining 2.6%, between 5 and 17 vessels. Vessel owners with one or two vessels have made up most of the bankruptcies that have come in the wake of the depression, since losses could not be balanced out as in the case of owners operating several vessels.

The contribution of the tuna fishery relative to total marine fishery production in Japan

The tuna fishery (longline and pole-and-line) production increased from a total 691,709 MT in 1963 to a peak of 740,969 MT in 1966, then hit a low of 546,802 MT in 1971. Accompanying the recent shift in fishing effort from longline fishing to skipjack pole-and-line fishing (Figure 1) the landings increased to 654,943 MT in 1973. In 1963, the tuna fishery accounted for 11.2% of the total marine fishery production in Japan (all species), but the contribution declined to 6.7% in 1973. Taking the two tuna fisheries separately, the contribution by the longline fishery decreased from 8.6% in 1963 to 3.1% in 1973. On the other hand, the skipjack tuna pole-and-line fishery increased its contribution from 2.6% in 1963 to 3.7% in 1973.

Although the tuna landings are relatively small in terms of total marine fishery production in Japan, they figure high in value. Tuna landings accounted for about 20% (average) of the total value of marine fishery production throughout the 10-year period. The landings by the tuna longline fishery, however, decreased from 17.6% of total value in 1963 to 13.7% in 1973, while the landings of the skipjack tuna fishery increased from 3.8% of total value in 1963 to 6.5% in 1973.

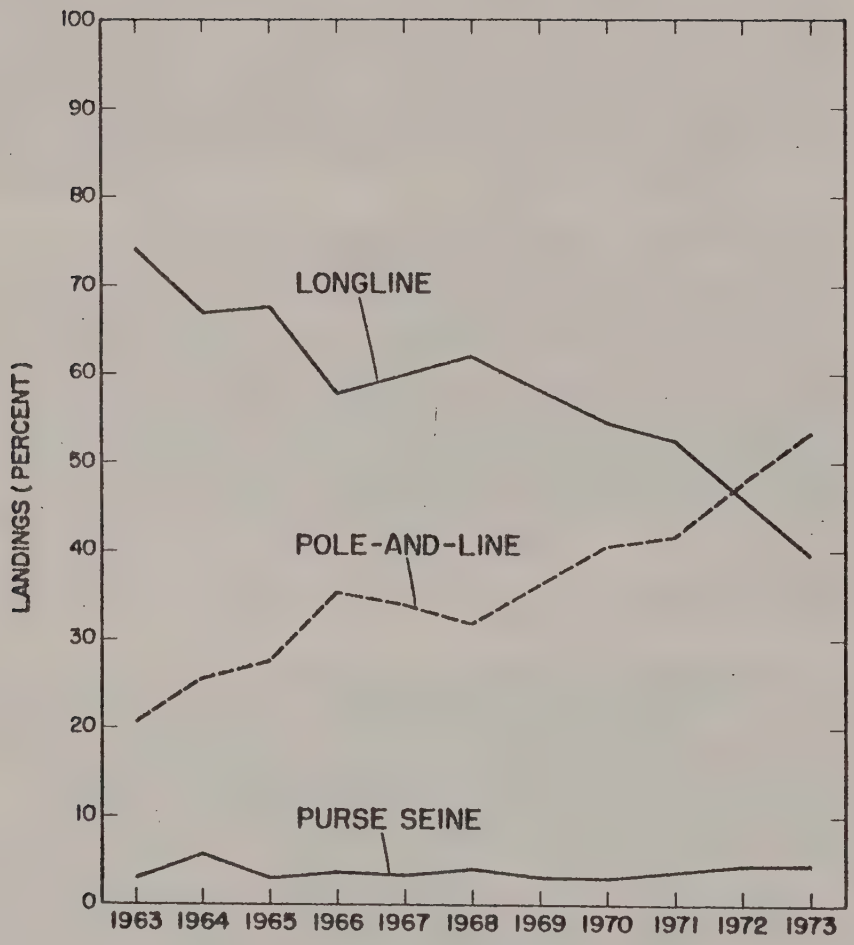


Figure 1.--The annual landings (percent) of tunas and billfishes in Japan by different fishing methods, 1963-73.

Declining catches in the tuna longline fishery

The main elements in the tuna longline fishery of Japan are the vessels in the 200-500 ton class. These vessels averaged around 1.8 MT of tuna per day of fishing in 1963. The catch has presently declined to approximately 0.8 MT per day, for a decrease of more than 50% in 10 years. Concomitant with this decrease in catch rate has been the lengthening of the fishing trips. In 1963 the vessels averaged 106 days of fishing per trip; in 1973, it was 259 days, or a 144% increase in 10 years.

The Japanese attribute this decrease in catch rate to greatly increased fishing effort for the larger tunas. There has been greatly increased longline fishing effort on the part of Korea, Taiwan, and Cuba, for example. There also has been increased surface fishing effort for tunas by United States, Spain, France, and Mexico. As an example, Korea had only 11 vessels fishing longline out of American Samoa in 1963. That year these vessels made 50 trips and took about 3,102 MT of tunas. Taiwan had 54 vessels catching 9,607 MT of tunas. At present, however, Korea has increased its longline fleet to 568 vessels; Taiwan may have close to 700 vessels. Thus the combined longline fleets of these two countries far exceed the Japanese longline fleet in numbers.

The Japanese tuna longline vessels no longer fish for albacore and yellowfin tuna intended for export as raw materials for canning. Most of the tuna vessels have been pulled out of foreign bases (e.g., American Samoa) and have been converted to the "sashimi fleet." Thus, the foreign-based operations for albacore and yellowfin tuna now depend upon Korean and Taiwanese longline vessels, mostly the latter.

As catch rates declined over the years, the Japanese vessel owners invested in larger vessels that could operate in more distant waters, and in expensive freezing equipment capable of reaching as low as -60°C. The result was that the vessels could now bring back to Japan fish of very high quality that would be suitable for use as sashimi or sushi. These fish commanded higher prices that tended to offset the losses from decreasing catch rates. Furthermore, to make operations less costly, labor saving devices such as the line-winder machines were adopted by many vessels, thus effecting a reduction of manpower.

However, sales of high-quality sashimi fish in Japan have been slow in the last year due to overall recession in the Japanese economy. This has been particularly noticeable in the slow-down in sales to high-class restaurants and sushi shops.

Major problems in the skipjack tuna pole-and-line fishery

The Japanese southern water skipjack tuna fishery experienced two very poor seasons in succession, mainly attributable to very high bait mortality. Thus, this fishery continues to be plagued with baitfish problems. Furthermore, the coastal water fishery was also very poor in 1975. One report indicated that there was a decrease in average landings of skipjack tuna per vessel of from 358 MT in 1974 to 270 MT in 1975, or a decrease of 75%. Operating costs during the period increased by 106.7%. Obviously, the skipjack tuna pole-and-line fishery is also having its problems.

Returning to the baitfish problem, the skipjack vessels depended on natural circulation of water in their baitwells prior to 1965. The baitfish survived only for a short period, and so the fishing trips tended to be short. Fishing grounds were necessarily limited to coastal waters, and catches fluctuated greatly, depending on how well the baitfish survived. It was around 1965 when the forced-circulation system was introduced. This development resulted in a great increase in the length of time that baitfish could be held alive in the baitwells, and enabled vessels to make longer trips to more distant waters. The skipjack tuna fishery expanded to southern waters soon thereafter, and it then became possible to fish for skipjack tuna on a year-round basis.

Around 1972, when it became evident that the larger tunas were being fished at or near the maximum level, the Japanese implemented a national program to shift the fishing effort from longline fishing to skipjack tuna pole-and-line fishing. There was a shifting of tonnages from longline to skipjack tuna vessels, and there also was a building boom for larger skipjack tuna vessels. Landings of the pole-and-line fishery started to increase greatly around this time.

About 70% of the landings of the skipjack tuna pole-and-line fishery is made up of skipjack tuna, about 20% of albacore, and the remainder os various other species (bluefin tuna, yellowfin tuna, bigeye tuna, and frigate mackerel (Table 1). Up to now, most of the catches of this fishery have either been exported or processed in various ways, and very little has been utilized as fresh fish. Thus fish prices have continued relatively low for fish caught by this fishery. For example, between 1963 and 1973, longline-caught tunas increased in average price by 400% to 529 yen/kg ($0.91 per pound). In comparison, pole-and-line fish increased by only 212% to 206 yen/kg ($0.36 per pound). In order to improve the situation in the pole-and-line fishery, various measures have been taken. An intensive effort has been made to improve bait-holding capabilities. Most of the larger ships have been equipped with freezing equipment that enables them to freeze their catches to around -30° or -40°C. This makes it

Table 1.--The landings by the Japanese skipjack tuna pole-and-line fishery, 1971-73.

Year	Total landings	Bluefin tuna	Albacore	Bigeye tuna	Yellowfin tuna	Small yellowfin tuna	Skipjack tuna	Frigate mackerel	Others
	Metric tons								
1971	230,098 (100.0%)	740 (0.3%)	52,957 (23.0%)	931 (0.4%)	2,570 (1.1%)	5,729 (2.5%)	157,380 (68.4%)	8,086 (3.5%)	1,705 (0.7%)
1972	291,054 (100.0%)	472 (0.2%)	60,591 (20.8%)	2,364 (0.8%)	4,287 (1.5%)	8,711 (3.0%)	199,836 (68.7%)	12,288 (4.2%)	2,505 (0.9%)
1973	358,857 (100.0%)	179 (0.1%)	68,808 (19.2%)	852 (0.2%)	8,600 (2.4%)	9,839 (2.7%)	254,259 (70.9%)	12,379 (3.4%)	3,940 (1.1%)

Data provided by Mr. M. Honma, Far Seas Fisheries Research Laboratory.

possible to bring back to Japan frozen fish of much better quality. In fact, some small use is now being made of frozen southern water skipjack tuna as sashimi, a new development in Japan. Many of the skipjack tuna vessels have reduced manpower in order to lower operating costs; some have installed automatic fishing machines that enable them to reduce manpower still further (Table 2). Another big step, already mentioned was the intensive promotion of canned albacore for domestic consumption.

Table 2.--Number of fishermen (average per vessel) on Japanese skipjack tuna vessels, by size class, 1964-73.

Year	30-50 tons	50-100 tons	100-200 tons	200-500 tons
1964	26.0	36.0	47.5	44.5
1965	24.5	35.0	44.5	43.0
1966	25.0	31.0	42.5	40.5
1967	23.5	31.5	42.5	39.5
1968	--	30.0	39.5	37.5
1969	22.5	25.0	35.0	34.5
1970	22.0	23.0	35.0	34.5
1971	21.0	23.0	35.3	35.1
1972	22.3	23.7	34.8	35.7
1973	21.8	22.8	28.7	32.4

Unpublished data provided by Dr. R. Ishida, Tohoku Regional Fisheries Research Laboratory

Foreign imports

In early 1974, just as the industry was beginning to recover from the mercury shock, fish prices suddenly started to decline. It was around this time that foreign imports of tunas and billfishes first began to appear in Japanese ports, mostly in the form of direct deliveries by foreign vessels. This has served to depress prices further in the Japanese market. The bulk of the foreign vessels are Korean, and ironically, most are former Japanese vessels that had been traded in by Japanese owners when they built larger vessels. These vessels had been bought by Japanese trading companies who in turn sold the vessels to Koreans.

In 1974, the imports amounted to 3.5 times the volume imported in 1970. In 1975, Japan imported 110,065 MT of tunas and billfishes, of which Korea delivered 59,139 MT, Taiwan 25,460 MT, and Panama (mostly crewed by Korean fishermen) 6,341 MT. The United States contributed 1,692 MT (619 MT of bluefin tuna, 608 MT of other tunas, and 451 MT of billfishes).

In December 1974 there happened to be 38 foreign vessels in the port of Shimizu. When Japanese vessels returned to port they could not even find docking space, let alone make arrangements to unload their catches. The freezer spaces had been taken up by foreign imports and fish prices dropped drastically. These were the conditions that brought Japanese fishermen "up in arms," culminating in a series of loud demonstrations demanding that the government restrict foreign imports. Some agreement has apparently been reached between Korea and Japan; the latest information is that the Koreans have agreed to a 45,000 MT quota for direct delivery of tuna to Japan.

Increase in foreign imports related to United States market

With the virtual closing of the United States market in 1974-75, those foreign vessels (particularly Taiwan and Korea) that had been catching tuna mainly for export as raw materials for canning, found themselves without their principal market. They rapidly turned their effort towards fishing tuna for the sahimi market in Japan, perhaps at the prodding of the Japanese trading companies holding interest in these vessels. They began fishing for bigeye tuna in particular, since these fish are in demand in the Japanese sashimi market, and their fishing grounds are relatively accessible. During the last half of 1975, a total of 60,519 MT of tunas and billfishes were imported (Korea, 35,067 MT; Panama, 5,188 MT; Taiwan, 12,000 MT). Imports had increased by 94% over the same period of the previous year.

It is now said that regardless of the outlook in the United States market, many of the Korean vessels will continue to fish for the Japanese market. This is because the Koreans have built many new vessels equipped with expensive freezing equipment specifically for the Japanese sashimi market. Furthermore, there is a considerable price differential between export fish and Japanese sashimi fish, the latter bringing the better price. Thus, it appears that the Japanese fishermen will be faced with stiff competition for their own market for years to come.

Status of the Japanese tuna industry

It is reported that about two-thirds of the Japanese longline vessels are presently operating either marginally or "in the red." One of

the biggest factors responsible for this is the great increase in labor costs. On Japanese vessels it has been reported that 50% of total operating costs involve labor costs, as compared to 10% on Korean vessels. It is no wonder that the Japanese tuna industry's competitive position in the world tuna market has so weakened over the last few years. (As an aside, it might be mentioned here that two-thirds of all businesses in Japan are reported to be operating in the red at this time.) A recent survey of tuna vessel owners indicated that many are now operating at a level that, if continued, is certain to lead to bankruptcy.

B. THE TUNA LONGLINE FISHERY OF TAIWAN AND KOREA

According to a reliable source in Japan, there are presently 680 tuna longline vessels (larger than 50 tons) in Taiwan. Of these, about 270-280 vessels have been tied up since the oil shocks of a few years ago. With the recent increases in export prices, many of the owners of these inactive vessels are now attempting to get them back to sea. The problem they face, however, is that of recruiting crew members. Former fishermen have found jobs ashore and are reluctant to return to sea.

While prices are generally up, the catch rates are low. The catch rate in the South Pacific, according to Taiwan statistics, is around 0.7 MT per day. It is around 1.5 MT per day in the Atlantic, and considerably lower in the Indian Ocean. They say that the break-even point for their vessels is around 1.0 MT per day (the figure would be higher for Japanese vessels because of the higher labor and fuel costs in Japan). Fuel costs around $90 per ton in Taiwan as compared to $100-$110 per ton in Japan.

In Korea there reportedly are 568 tuna longline vessels operated by 73 vessel owners (average 7.8 vessels per owner). The total vessel tonnage is 157,974 tons. Although there are more tuna vessels in Taiwan than in Korea, the Korean vessels are larger and exceed the Taiwan fleet in total tonnage.

As for reactivating tuna vessels that have been tied up to the docks, it is said that Taiwan boat owners are better able to do this than Koreans because they have ready access to short-term credit from banks and Japanese trading companies. It appears that it is much more difficult financially for Korean tuna vessel owners to reactivate their ships.

Most of the Korean tuna longline vessels are now being used to catch tunas for the Japanese sashimi market. Only a few vessels are left in foreign ports (e.g., Samoa and Abidjan). One report indicates that there are 230 vessels in the Korean fleet mortgaged to Japanese trading companies (these are 250-ton vessels). Most of the Taiwan

vessels are smaller (150-ton class), and fish mainly for export (albacore). Yellowfin tuna is no longer a profitable fish to them ever since Italy began to purchase Atlantic yellowfin tuna from French and Spanish purse seiners, thereby causing the Italian import price for yellowfin tuna to decline drastically.

Instead of tying up their vessels and releasing the crews, however, some Taiwan owners continued to operate by shifting over to fishing for sharks in the Bay of Bengal, or gillnetting for wahoo around Guam and Indonesia. Some of these fish are being consumed in Taiwan, others are being exported to Japan. These vessel owners are in the best position to switch back to tuna fishing because they were able to retain their crews.

Fishing for sashimi fish is far more profitable than fishing for albacore, but the Taiwanese have not entered the sashimi market in great numbers. The reason given for this was that Taiwan fishermen are "warm climate people" and are most reluctant to fish in cold waters where sashimi fish abound. It was stressed that Taiwan fishermen are even reluctant to work in the ships' reefers, which is necessary if they fish for sashimi fish.

C. JAPANESE SOUTHERN WATER SKIPJACK TUNA FISHERY, February-December 1975

The following is a preliminary summary of the recent fishing situation in the Japanese southern water (south of lat. 24°N) skipjack tuna fishery as prepared by Mr. Tamotsu Tanaka, Yaizu Branch Office of the Tohoku Regional Fisheries Research Laboratory. A final report, together with charts, will be forthcoming from the Tohoku Laboratory, at which time a separate translation will be issued. Data on the landings of southern water skipjack tuna in Yaizu between July 1974 and May 1975 are given separately in Table 3.

February 1975

The very good fishing experienced in waters east of the Solomons a year ago did not materialize this year; the catches rarely reached the maximum of 20 tons per day, and average catches were on the order of 2-4 tons per day. The surface water temperature ranged from 28.9°-30.0°C. Similarly, poor fishing was experienced in waters extending from around Manus Island to the vicinity of New Hanover Island.

Skipjack tuna taken in waters north of the Solomon Islands showed the following size composition: larger than 4.5 kg, 2.6%; 2.5-4.4 kg, 85.1%; and 1.5-2.4 kg, 12.3%. In the Solomon Sea area, the fish sizes were: larger than 6.8 kg, 0.8%; 4.5-5.9 kg, 7.6%; 2.5-4.4 kg, 63.2%; 1.5-2.4 kg, 28.0%; and smaller than 1.4 kg, 0.4%. There were 60-70 vessels fishing in the Solomon Sea area.

Table 3.--The landings of southern water skipjack tuna at Yaizu port during the 1974 fishing season (July 1974-May 1975).

Year	Month		No. of vessels	Amount landed	Landings per vessel
				MT	MT
1974	July		12	751.4	62.6
		W	4	721.8	180.4
	August		61	5,675.5	93.0
		W	6	655.0	109.1
		P	1	[1]192.2	
	September		50	4,310.6	86.2
		W	1	106.5	106.5
	October		96	7,914.7	82.4
	November		78	6,526.9	83.6
	December		95	7,948.7	83.6
		P	1	[2]63.3	
1975	January		23	2,494.9	108.4
	February		41	4,354.4	106.2
	March		113	11,040.0	97.6
	April		100	11,093.1	110.9
	May		39	4,298.7	110.2
		P	1	[3]247.8	

W = Fishing ground east of 180°.

P = Purse seiner landings.

[1]Includes 83.5 MT of small yellowfin tuna.

[2]Includes 30.6 MT of yellowfin tuna.

[3]Includes 60.2 MT of small yellowfin tuna, 2.2 MT of large yellowfin tuna, and 5.3 MT of small bigeye tuna.

In waters east of long. 180°, a good fishing ground developed around lat. 6°-8°N, long. 180°-173°W, where the water temperature ranged from 27.4° to 27.8°C. The maximum day's catch per vessel reached 30-40 tons; the average was around 6-7 tons per day. Towards the end of February, fishing also improved in adjacent waters west of long. 180°, where catches exceeded 10 tons per day, showing a western extension of the fishing ground. Fish sizes were: larger than 6 kg, 27.2%; 4.5-5.9 kg, 58.3%; and 2.5-4.4 kg, 14.4%. Most of the catch consisted of fish larger than 5 kg. There were about 20 vessels fishing in this area.

Some fishing also took place in waters south of lat. 10°S by vessels larger than 400 gross tons:

1) In mid-February, one vessel fished near Tahiti at lat. 14°S, long. 145°W, where the water temperature was 28.7°-29.0°C.

2) In late February, five or six vessels fished near Fiji at lat. 15°-16°S, long. 178°-179°E, where the water temperature was 29.0°-29.4°C.

3) In late February two or three vessels fished near New Caledonia at lat. 19°S, long. 160°-163°E, where the water temperature was 28.6°-29.2°C. The results of these operations are given in greater detail in the report for March.

March 1975

In early and mid-March, 30 to 40 vessels fished in the Solomon Sea (lat. 7°-12°S, long. 153°-160°E), where the water temperature ranged from 29.5° to 30.0°C. The best catches were around 15-20 tons per day; the average was around 4-5 tons per day per vessel. Toward late March, the average catch increased slightly to around 6-8 tons per day, but only about seven or eight vessels were fishing this area by then. Fish sizes were: larger than 4.5 kg, 10.6%; 2.5-4.4 kg, 63.6%; 1.5-2.4 kg, 25.2%; and smaller than 1.4 kg, 0.5%.

In waters east of long. 180°, fishing during early March centered around lat. 7°-8°N, long. 175°-178°W. However, after mid-March, the effort shifted toward the Marshalls to lat. 9°-13°N, long. 165°-173°E, where the water temperature was 26.5°-27.9°C. Here, the maximum catch reached 72 tons per day, with numerous catches of 15-20 tons per day. As a result of this good fishing, many vessels moved into the area. The catches averaged 7-8 tons per day for the 40-50 vessels that fished this area. The sizes of skipjack tuna taken were: larger than 6 kg, 48.8%; 4.5-5.9 kg, 34.0%; 2.5-4.4 kg, 13.8%; and 1.5-2.4 kg, 3.2%. Most of the fish were large fish. There were very many skipjack tuna schools associated with whale sharks in this area.

Furthermore, many vessels returning to Japan from this area paused in the vicinity of Wake Island (lat. 15°-16°N, long. 165°-166°E; water temperature, 26.9°C) to fish skipjack tuna using what bait was left in the bait tanks. Here some vessels reported taking 15-20 tons per day of 8-13 kg skipjack tuna. Many vessels fished near Wake Island on their way home and reported taking around 10 tons of skipjack tuna per day. For this time of the year, our records indicate that these were unusually good catches for the Wake Island area.

From mid-February, fishing continued around Tahiti, Fiji, and New Caledonia, and the results were as follows:

1) Tahiti (lat. 14°S, long. 145°W).

Fishing in mid-February resulted in catches of up to 35 tons per day. The skipjack tuna were generally small, ranging from 1.5 to 3.0 kg, and most of the schools appeared to be "shoal associated." Also, at lat. 10°S, long. 148°-149°W, catches of 10-15 tons per day (maximum of 20 tons per day) of 10-15 kg skipjack tuna were reported. It is anticipated that this area may become a good fishing ground in the future. Only one vessel fished these waters.

2) Fiji (lat. 15°-16°S, long. 178°-179°E; water temperature, 29.0°-29.4°C).

Five or six large vessels fishing these waters caught as much as 25-30 tons per day beginning in late February. The skipjack tuna taken were generally small fish of 1-3 kg. In this area, as in waters near Tahiti, most of the skipjack tuna schools appeared to be shoal-associated schools, and thus consisted mainly of small fish. Toward the end of March, one vessel ventured off to fish around lat. 10°S, long. 180°, and caught around 10 tons per day.

3) New Caledonia (lat. 19°-20°S, long. 160°-165°E; water temperature, 28.6°-29.2°C).

Three large vessels fished this area and made good catches of 10-29 tons per day beginning in early February. However, bad weather tended to hamper fishing most of the time. There appeared to be large numbers of yellowfin tuna schools in these waters. Fish sizes were: larger than 12 kg, 27.0%; 6.0-11.9 kg, 31.0%; 4.5-5.9 kg, 8.7%; 2.5-4.4 kg, 24.3%; and 1.5-2.4 kg, 8.7%.

April 1975

The Marshall Islands area developed into a good fishing ground during this month. At lat. 7°-13°N, long. 157°-168°E (water temperature,

26.6°-27.8°C), the maximum catches in early and mid-April were around 25-30 tons per day; the average was around 6-7 tons per day. Toward the latter part of the month, however, many vessels departed the area after learning that the albacore fishing season in Japanese coastal waters was beginning. Many of the vessels switched over to albacore fishing at this time. A few, however, remained to fish skipjack tuna in waters west of Wake Island and near Uracus Island in the Marianas.

In the waters west of Wake Island the maximum catches were around 14-15 tons per day, with an average catch of around 5-6 tons per day. Fish sizes ranged from 3 to 10 kg (4 to 8 kg fish were dominant). In the Marianas, the maximum catches were around 15-16 tons per day, and the average was around 5-6 tons per day. The fish were 3 to 9 kg in size. In this area, there were 10-15 smaller vessels of the 59-ton class fishing alongside the larger vessels. There were an estimated 70 to 80 vessels operating in the Marshall Islands area.

In the northern Marshalls, the fish sizes were: larger than 6 kg, 55.6%; 4.5-5.9 kg, 26.4%; 2.5-4.4 kg, 15.0%; and 1.5-2.4 kg, 3.0%. In the southern Marshalls, fish sizes were: larger than 6 kg, 19.0%; 4.5-5.9 kg, 43.8%; 2.5-4.4 kg, 29.2%; and 1.5-2.4 kg, 7.8%.

After mid-April, large fish (larger than 6 kg) decreased in numbers, and at the same time there was a noticeable increase in the 2.5, 4.5, and 5.0 kg groups. It was reported that the larger fish were more abundant in the northern parts of this fishing ground.

May 1975

Three or four vessels fished in the Solomon Sea (lat. 7°-11°S, long. 150°-157°E) and reported catches of up to 12-13 tons per day. The average catch was around 3-4 tons per day. The sizes of skipjack tuna taken were unchanged from the previous month and ranged from 1.5 to 3.5 kg. Also, at lat. 9°-11°S, long. 165°W-179°E (between Tokelau Islands and Ellice Islands), two vessels caught an average of 4-5 tons per day. The skipjack tuna taken were: larger than 6 kg, 40.4%; 4.5-5.9 kg, 13.0%; 2.5-4.4 kg, 39.7%; and 1.5-2.4 kg, 6.8%.

The purse seiner, Fukuichi Maru (499 tons), chartered by the Japan Marine Fishery Resource Research Center (JAMARC), fished around log-associated schools at lat. 0°, long. 138°-141°E between late April to early May, and in 12 days of fishing caught 248 tons of fish (180.1 tons of skipjack tuna, 5.3 tons of small bigeye tuna, 60.2 tons of small yellowfin tuna, and 2.2 tons of large yellowfin tuna).

Towards late April, vessels from Kagoshima Prefecture reported catching 10-20 tons per day of large skipjack tuna (6-9 kg) at lat. 13°-14°N, long. 142°-144°E. These vessels reportedly continued fishing this area until early May.

June 1975

In June skipjack tuna fishing was widespread in subtropical waters extending from the Marianas to Minami-Torishima (Marcus) and to Wake Island (lat. 16°-21°N, long. 142°-170°E). There were more vessels that arrived there after quitting albacore fishing earlier than in previous years.

Usually, vessels do not leave the albacore fishery so early in the season. This year, there were about 50-60 vessels fishing these waters by the end of the month. In the Marianas (lat. 19°-21°N, east of long. 160°E) the water temperature was higher than normal at 29.5-30.4°C. Perhaps because of this, baitfish (anchovy and sardine) mortality was very high at 40%-50%. The mortality was highest in baitfish that had been brought south directly from the albacore grounds. Perhaps this indicated that very large baitfish (10-15 g per fish) such as are used in the albacore fishery are unsuitable for southern water skipjack tuna fishing. This may be because large baitfish cannot tolerate the high temperatures in southern waters, or because these fish are in a weakened condition following spawning.

In the Marianas west of long. 160°E, there were also some reports of high baitfish mortality, but here the vessels were making catches of 20-25 tons per day (average 6-7 tons per day). Fish sizes were: 1-2 kg, 10%; 3-4 kg, 60%; and 6-8 kg, 30%. Toward the eastern part of this area (lat. 19°N, long. 169°E) the water temperature was around 27°-28°C. Here vessels continued for a while to catch 10-15 tons per day of large skipjack tuna. Fish sizes were: larger than 9 kg, 28%; 6 kg, 20%; 4.5 kg, 2%; and 2.5 kg or smaller, about 50%.

There were three or four vessels fishing to the east of long. 180° at lat. 24°-29°N, long. 166°-179°W (water temperature, 21.0°-26.5°C) in the area extending from Midway toward the Hawaiian Islands. Most of the skipjack tuna taken were small fish (1.5-3.0 kg), and the 9-15 kg skipjack tuna taken in these waters in previous years were not encountered. The maximum catch per day was 36 tons; the average was around 10-15 tons per day, including yellowfin and bigeye tunas.

The chartered purse seiner Fukuichi Maru (499 tons) fished experimentally in southern waters beginning in late May. The trials centered around lat. 3°-7°N, long. 135°138°E and also around lat.

0°, long. 138°-139°E. In 17 sets of the seine, the vessel took 182.9 tons of skipjack tuna, 41.1 tons of large yellowfin tuna, 54.3 tons of small yellowfin tuna, and 4.9 tons of small bigeye tuna. As usual, the vessel aimed her sets around schools associated with drifting logs. However, this may have been the first time in which sets were made on six consecutive days around the same log-associated school.

In June, 15 vessels unloaded 1,185.2 tons of southern water skipjack tuna (including 11 tons of small yellowfin tuna) at Yaizu. The landings per vessel averaged 79.7 tons. Another vessel that fished in southern waters to the east of long. 180° returned with 202.9 tons (including 25.6 tons of small yellowfin tuna, and 3.6 tons of small bigeye tuna). One purse seiner unloaded 182.9 tons (including 41.1 tons of large yellowfin tuna, 54.3 tons of small yellowfin tuna, and 4.9 tons of small bigeye tuna).

July 1975

Fishing grounds developed extensively throughout the subtropical area east of the Marianas at lat. 19°-21°N, long. 145°E-170°W. In waters west of long. 160°E, the water temperature was just as high as in June (29.4°-30.0°C). To the east of long. 160°E, it was around 28°C. In waters east of long. 180°, the temperature was around 27°C. Whether related to temperature or not, there were reports of higher bait mortality among vessels operating in high-temperature waters west of long. 160°E.

In the area long. 179°E to 170°W, the catches reached a maximum of 40-50 tons per day of large (8-15 kg) fish. Along with these large fish, some 1.5 kg fish were also taken. In the area long. 160°-165°E, the maximum catches were 20-25 tons per day of 3.0-3.5 kg and 8-13 kg skipjack tuna. In the vicinity of long. 153°E, the maximum catch was 30 tons per day of mostly 3.0-3.5 kg skipjack tuna. There were also some 1-2 kg and 8-13 kg fish taken in the area. Finally, near long. 145°E, the catches reached 30-35 tons per day of largely 2-4 kg skipjack tuna, along with some 7-8 kg fish. In general, the average catch throughout the extensive subtropical area was around 6-7 tons per day and was considerably better than the same time a year ago. Since this area appeared to yield a steady, reliable harvest, about 150 vessels fished there, while only four or five vessels ventured farther south at this time. Although there were some vessels that fished the shoal-associated fish in the vicinity of the Marianas, catches there only averaged around 3-5 tons (maximum 10 tons) of 1.5-2.5 kg fish per day.

Those few vessels which ventured south fished at lat. 1°-2°N, long. 149°-150°E (water temperature, 29.0-29.4°C) and experienced catches of 10-20 tons per day but only for a few days. The catches soon

turned poor. At lat. 0°, long. 138°-139°E, catches were again from log-associated schools and amounted to 10-15 tons per day. However, here again, good fishing was of short duration. A few vessels shifted to areas east of long. 180° to fish shoal-associated schools, but the results were disappointing.

Towards the end of July, the vessels fished log-associated schools at lat. 5°-6°N, long. 170°-175°E and made good catches of around 40 tons per day.

In July, 47 vessels returned from southern waters to unload 3,799.1 tons of skipjack tuna at Yaizu. This included 44.2 tons of small yellowfin tuna and bigeye tuna. The landings per vessel averaged 80.4 tons. There were 192.7 tons of fish taken from waters east of long. 180°.

August 1975

As fishing became unproductive throughout the subtropical waters (along lat. 20°N), vessels began to scout areas south of lat. 10°N. Toward the end of July excellent fishing had been experienced on log-associated schools at lat. 4°-5°N, long. 170°-173°E (water temperature, 28.4°C) with catches of 40-60 tons per day. After initial reports of good catches, vessels had flocked to the area and catches had fallen to 20-30 tons per day from both log-associated and other types of schools. Fish taken from log-associated schools showed the following size composition: larger than 6 kg, 7.4%; 4.5 kg, 21.3%; 2.5 kg, 35.9%; and 1.5 kg, 35.4%. Sizes of fish taken from other types of schools were: larger than 6 kg, 13.1%; 4.5 kg, 39.8%; 2.5 kg, 42.9%; and 1.5 kg, 4.2%.

Toward the end of this month, the fishing grounds shifted slightly to the west to lat. 4°-5°N, long. 165°-168°E (water temperature, 28.5°C), where average catches of 7-8 tons per day were experienced. There were 40-50 vessels fishing this area.

In the Carolines, where fishing remained poor until mid-August, there was a definite improvement towards the end of the month. At lat. 3°-5°N, long. 148°-150°E (water temperature, 28.5°C), 10-22 tons of 3-5 kg skipjack tuna were caught per day. Vessels moving toward the east paused here to fish, and there were 20-30 vessels in the area by late August.

Baitfish mortality increased sharply as the vessels moved southward beyond lat. 10°N. The mortality was particularly marked on vessels that had departed Japan after mid-August, and many of these vessels reported mortalities of 70%-90%. They had obtained their bait mainly from the baiting areas along the west coast of Kyushu (Yokoura, Miyanoura, Kohama, etc.) and also from Sajima in Kanagawa

Prefecture, but bait mortality did not seem to differ between baiting areas. The baitfish appeared healthy at first glance but there were instances when the bait died little by little each day after departure from Japan, and also cases where the baitfish survived all the way to the fishing grounds and suddenly succumbed to mass mortality. There are at present no certain countermeasures against such heavy mortalities.

In August, 69 vessels arrived in Yaizu from southern waters to unload 7,906.6 tons of skipjack tuna (including 152.6 tons of small yellowfin and bigeye tunas) for an average of 114.5 tons per vessel.

September 1975

Throughout September fishing took place in the Marshalls and near Kusaie Island (lat. 5°-10°N, long. 165°-175°E), where the water temperature was 27.5°-28.7°C). There was also some fishing farther to the east but catches were not very good. In the main fishing grounds near the Marshalls, the best catches were around 25 tons per day with a daily average of 4-5 tons. Although the catches were not spectacular, fishing was steady. The fish taken were: 6-10 kg, 21%; 4-5 kg, 47%; and 1-2 kg, 32%. There were 60-70 vessels fishing in this area.

The Carolines continued to show poor fishing throughout the month. Even where large numbers of schools had been seen a month ago at lat. 3°-5°N, long. 148°-150°E, the fishing was very poor this month. The Kagoshima Prefecture vessels, which usually fish the Carolines area, shifted their operations to waters east of long. 160°E.

The baitfish mortality continued high. According to reports of vessels that had departed Japan in mid-August and returned to Yaizu this month, there were cases of mortalities as high as 90%.

In September, 83 vessels unloaded 7,817.6 tons of skipjack tuna (including 256.0 tons of small yellowfin and bigeye tunas) at Yaizu for an average of 94.2 tons per vessel. One purse seiner returned with 199.3 tons of skipjack tuna, 80.2 tons of large yellowfin tuna, 20.6 tons of small yellowfin tuna, and 5.7 tons of other species.

October 1975

Baitfish mortality continued to be high. Although some fishing took place in the Carolines and Marshalls, no satisfactory operations were possible because of the heavy bait mortalities. In the Carolines at lat. 4°-6°N, long. 144°-157°E (water temperature, 29.5°-

30.0°C), considerable numbers of skipjack tuna schools were sighted but because of the shortage of bait (from mortality) and also because skipjack tuna responded poorly to the chummed bait (probably because it included too many dead baitfish), only about 2-8 tons per day of fish were taken. The skipjack tuna taken were between 2-5 kg in size. There were 30-35 vessels in the area.

In the Marshall Islands area at lat. 6°-13°N, long. 162°-175°E (water temperature, 28°C) catches were around 3-10 tons per day and these low catches were again attributable to bait mortality. The skipjack tuna taken ranged from 4 to 12 kg (6-12 kg fish dominant) but there were also large numbers of 1.5 kg fish taken (about 30%). It is interesting to note the sighting of large schools of juvenile skipjack tuna of around 25 cm (250-300 g) in this area.

Also, large numbers of schools of small skipjack tuna of 0.5-1.5 kg were reported to the west of long. 140°E near Palau.

In October, 87 vessels returned to Yaizu from southern waters to unload 5,523.6 tons of skipjack tuna (including 198.8 tons of small yellowfin and bigeye tunas); the average delivery per vessel was 63.5 tons. This low average reflected the effect of heavy bait mortality experienced by many of the vessels.

November 1975

At lat. 5°-12°S, long. 175°-180°, (water temperature around 27°C), five or six vessels operated with maximum catches of 20-25 tons per day. The fish taken were large (5-13 kg) skipjack tuna. The average catch was around 5-8 tons per day. When compared with other areas with very poor fishing, this area was relatively productive, resulting in as much as 180-220 tons per trip for several of the larger (more than 400 tons) vessels.

The skipjack tuna vessels that fished the Coral Sea this year did not do well at all, averaging only around 40 tons per vessel (per trip). Two purse seiners fishing in the Coral Sea took only about 250 tons of fish each.

The main fishing grounds in November developed around lat. 4°-6°N, long. 146°-160°E (water temperature 29.0°-29.5°C). In mid-November, the vessels were taking a maximum of 20-25 tons per day with an average of 7-8 tons per day. Toward the end of the month, however, fishing conditions deteriorated rapidly and only about 3 tons per day could be caught on the average. Most of the fish taken were around 3-5 kg. The chartered purse seiner Fukuichi Maru fished this same area and found fishing very poor at this time.

In the vicinity of the Marshalls, at lat. 9°-13°N, long. 165°-175°E (water temperature 28.0°C), rather good catches were reported in early and mid-November. The maximum catches amounted to 20-25 tons per day; the average was 5-6 tons per day. Again, fishing turned poor toward the end of the month. The vessels started to shift westward. Some of the larger vessels headed for waters south of the equator.

It was reported that the vessels based in the Solomons and in New Britain were also experiencing extremely poor fishing at this time.

In November, 78 vessels unloaded 6,592.4 tons (including 438 tons of small yellowfin and bigeye tunas) of southern water skipjack tuna at Yaizu. The average landings per vessel amounted to 84.5 tons. In addition, two purse seiners landed 406.3 tons of skipjack tuna, 114.8 tons of large yellowfin tuna, and 64.9 tons of small yellowfin and bigeye tunas for a total of 586.0 tons.

December 1975

Fishing conditions in waters east of long. 160°E deteriorated very rapidly and most of the vessels shifted their operations to waters west of long. 150°E. In early December, some catches of up to 20 tons per day were made in the area northwest of Truk (lat. 8°-9°N, long. 149°-151°E, water temperature 28.2°C). The skipjack tuna were mainly large fish of 6-8 kg. However, starting in mid-December, although fish schools were encountered, the fish responded very poorly to chum. Most vessels then shifted westward. In mid-December, at lat. 2°-4°N, long. 142°-147°E (water temperature, 29.4-29.5°C), some vessels fished log-associated schools and caught up to 14-15 tons per day (average 3-5 tons) of 2-4 kg skipjack tuna. About 20%-25% of the catches comprised of 1-2 kg skipjack tuna, indicating an increase in smaller fish in the area.

Towards late December, many vessels moved westward and fished around lat. 2°-5°N, long. 132°-136°E (water temperature 29.3°-29.5°C), aiming mainly at log-associated schools. The maximum catches were around 20 tons per day (average 5-6 tons) of small skipjack tuna (about 30%-50% were 1-2 kg fish). Also, at lat. 0°, long. 139°-143°E (water temperature 29.5°-29.8°C), five or six vessels fished log-associated schools and made good catches of 10-25 tons per day. These vessels took 95-185 tons (per trip) from this area. The fish were small, however, and ranged from 1 to 4 kg. Seventy percent of the catch consisted of 1-2 kg fish. Since virtually all fishing was done on log-associated schools, as expected there was a rather large proportion (4%-10%) of small yellowfin and bigeye tunas mixed in the catches.

There still were a few reports of heavy bait mortalities.

In December, 100 vessels delivered 8,315.0 tons (including 339.7 tons of small yellowfin and bigeye tunas) of southern water skipjack tuna at Yaizu. The average landings per vessel amounted to 83.1 tons. Four purse seiners landed 891.3 tons (including 297.9 tons of yellowfin and bigeye tunas).

D. TUNA PURSE SEINING

There are essentially three categories of purse seining in Japan. These are: 1) tuna purse seining (coastal and distant water); 2) seining for tunas and other species (coastal waters); and 3) seining for bigeye scad and mackerel (coastal waters). Here we are concerned with tuna purse seining only.

Tuna purse seining in tropical waters has improved considerably, and there are presently several commercial seiners operating in the western Pacific. The catch rates have improved significantly from last year's average of around 10 tons per set to around 16-20 tons. I was told that purse seiner captains are now able to evaluate quite accurately whether or not a school is seinable, thus increasing their percentage of success on sets made. They have begun to seine schools not only associated with drifting objects, but those associated with birds as well (Table 4).

Table 4.--Results of visual scouting for fish schools and fishing for skipjack tuna, Fukuichi Maru, 1975.

Type of schools (association)	Total schools sighted A	Skipjack tuna (present or absent)					
		Present B	B/A	Absent C	C/A	No. of sets made D	D/B
			%		%		%
Solitary	0	0	0	0	0	0	0
Birds	197	102	52	95	48	10	10
Drifting objects	177	80	45	97	55	45	56
Whales-sharks	5	1	20	4	80	0	0
Total	386	183	47	206	53	55	30

From: Data provided by JAMARC.

An interesting recent trend has been the conversion in the purse seine fishery from two-boat seining to one-boat seining (Table 5). Perhaps this trend is the consequence of the promising results obtained by the one-boat seiners which operated experimentally in tropical waters under charter to JAMARC. Another reason may be the lower costs involved in one-boat seining.

Table 5.--The landings, by species, of tunas by the Japanese purse seine vessels, 1968-73.

Year	Type	No. of vessels (units)	Species[1]						
			BF	AL	BE	YF	Small YF	SJ	FM
			Metric tons						
1968	One-boat	--	22	--	25	1,012	229	4,350	--
	Two-boat	--	5,989	66	158	3,059	2,305	2,301	--
1969	One-boat	16	14	41	48	489	17	5,714	3
	Two-boat	55	2,288	193	48	1,548	141	3,631	10
1970	One-boat	21	89	38	106	2,400	30	2,791	--
	Two-boat	49	1,660	124	77	2,386	361	2,484	7
1971	One-boat	29	46	151	167	2,197	119	8,626	--
	Two-boat	41	2,521	744	27	1,069	668	2,077	--
1972	One-boat	38	61	273	761	3,744	84	13,614	--
	Two-boat	34	3,352	2	--	746	264	1,239	3
1973	One-boat	43	353	1,326	189	5,880	467	16,301	7
	Two-boat	19	1,169	24	4	1,575	51	1,791	--

Data provided by Mr. M. Honma, Far Seas Fisheries Research Laboratory.

[1]BF = bluefin tuna; AL = albacore; BE = bigeye tuna; YF = yellowfin tuna; SJ = skipjack tuna; and FM = frigate mackerel.

One-vessel seining requires 19-22 men in the crew of a 500-ton seiner. Two-vessel seining requires 44-45 men in the crews of two vessels in each unit.

One of the newest one-boat seiners is the 500-ton Fukuichi Maru, which has 18 men in her crew.

In tropical waters, Table 6 shows an increasing success rate (successful sets/total sets) over the years. Since 1971, the success rate has been at around 60%. The total landings by the purse seine vessels have also increased considerably since 1973.

Table 6.--Tuna landings by Japanese purse seiners in southern waters, 1967-74.

Year	No. of vessels	No. of sets	No. of successful sets (percentage)	Species[1]				
				BE	YF	SJ	Other	Total
				Metric tons				
1967	3	42	12(28.6%)	--	120	130	1	249
1968	4	89	22(24.7%)	--	220	208	--	427
1969	2	22	8(36.4%)	--	3	77	--	80
1970	4	95	39(41.1%)	--	123	338	--	461
1971	5	115	82(71.3%)	35	200	706	3	944
1972	4	60	40(66.7%)	47	188	539	8	782
1973	6	197	111(56.3%)	84	412	1,245	10	1,752
1974[2]	7	353	-- --	36	407	2,159	19	2,621

Data provided by Mr. M. Honma, Far Seas Fisheries Research Laboratory.

[1]BE = bigeye tuna; YF = yellowfin tuna; SJ = skipjack tuna.

[2]Estimated.

The results of the most recent charter cruises were reported by JAMARC as follows:

Vessel: Fukuichi Maru, 499 tons

Survey area: Caroline Islands area, lat. 10°N-1°S, long. 135°-158°E.

Survey periods:

First cruise: Departed Yaizu 10 April 1975; returned Yaizu 17 May 1975.

Second cruise: Departed Yaizu 24 May 1975; returned Yaizu 27 June 1975.

Third cruise: Departed Yaizu 7 July 1975; in Guam 11-15 August 1975; returned Yaizu 17 September 1975.

Bad weather precluded fishing on 7 days during the survey period. There was an unusual number of squalls, which had some effect on visual scouting for fish schools. One-hundred eighty-three fish schools out of a total of 386 schools sighted contained skipjack tuna (Table 4). In 55 sets, 82% were on schools associated with drifting objects; the remainder (18%) were on schools associated with bird flocks. Last year only 4% of the sets had been made around bird-associated schools. The success rate this year in setting around bird-associated schools was 40%, indicating the feasibility of successfully fishing around this type of school in addition to schools associated with drifting objects. The first cruise resulted in an average catch of 19.6 MT of tuna per set; the second in 16.9 MT, and the third in 16.7 MT per set, thus exceeding the performance of a year ago by a considerable margin (Table 7). The total catch amounted to 959.2 MT as compared to the 500 MT taken during last year's charter cruise (June-November 1974). This year's results gave promise of the possibility for year-round purse seining in tropical waters.

Table 7.--Purse seining results of the Fukuichi Maru, 1975.

		Cruise			
		First	Second	Third	Total
Total No. of days per trip		38	35	65	138
No. of days on fishing grounds	A	23	24	50	97
No. of days fished (No. of sets)	B	13 (13)	15 (17)	23 (25)	51 (55)
B/A (%)		57	63	46	65
Total catch (MT)		254.2	287.5	417.5	959.2
Catch per set (MT)		19.6	16.9	16.7	17.4

Catch (MT)				
Skipjack tuna	184.2	185.8	288.2	658.2
Yellowfin tuna	62.4	92.6	123.6	278.6
Small yellowfin tuna	5.4	4.8	5.7	15.9
Others	2.2	4.3	0	6.5

Data provided by JAMARC.

E. SKIPJACK TUNA FISHERY SURVEY IN MICRONESIA

JAMARC again chartered the No. 20 Akitsu Maru (192 tons) to survey Micronesian waters. This was the second of three planned surveys in Micronesia. The first was conducted between 1 July and 15 October 1974, during which only Ponape was surveyed. The planned survey of Truk did not materialize because no agreement could be reached with local chiefs during pre-survey negotiations. The results of the Ponape survey were in general disappointing. The observers cited the following reasons: Bait was scarce and sufficient quantities could not be taken; this often precluded the vessel from fishing during the best hours of early morning and late afternoon. Furthermore, some of the baitfish (anchovies in particular) were very weak, some were stronger but too scarce (clupeids), and some, although rather plentiful and strong, were too big (carangids). The bait survey included the use of the stick-held lift net (bo-uke ami) and the drive-in net (oikomi-ami), the latter for taking reeffish.

The second survey was conducted between 21 May and 20 September 1975. Negotiations with local authorities were fairly successful this time and the survey included Ponape, Palau, and western Truk, with about a month spent at each locality. In general, the results showed that, of the three areas, only Palau abounded in baitfish. The situation in Ponape was unchanged from that of the first survey. Truk also revealed a scarcity of baitfish.

Bait surveys were conducted by bait fishing with the stick-held lift net (bo-uke ami). After the bait were taken, they were transferred into a bait receiver for holding tests. At Ponape, only a small bait receiver, 3 m x 3 m square, was used. The baitfish were swum into the receiver by lowering the edge of the receiver netting. After 26 h in the receiver, the 25 buckets of baitfish suffered an 80% mortality. Similarly, in Truk, 10 buckets of baitfish held in the bait receiver suffered a 60% mortality after 26 h. A longer holding experiment was conducted in Palau where a larger receiver, 9 m in diameter, 32 m deep, was set up in the lagoon. The vessel was anchored and the receiver placed next to it. After catching bait by stick-held lift net, the bait were transferred into the receiver. Small quantities

of bait were transferred each time to the receiver over a 5-day period. The bait survived well for more than 5 days. Ten days later, however, only 20 buckets of a total of 214 buckets remained alive, resulting in a 9.3% survival. Not all of the bait had died; considerable amounts were seen escaping from the receiver by jumping over the netting. The clupeid, Harengula ovalis, were particularly adept at escaping from the receiver. A factor contributing to the mortality was the large numbers of birds which constantly attacked the bait in the receiver.

In Ponape, 718 buckets of baitfish consisting mostly of Stolephorus heterolobus were taken over the survey period. The average catch per set of the lift net was 14.6 buckets. In Truk, 797 buckets were taken, averaging 17.7 buckets per set. Most of the bait consisted of Spratelloides delicatulus. In Palau, where the most bait was seen, 1,300 buckets were collected, mostly S. heterolobus, averaging 24.6 buckets per set.

According to the observer who accompanied the vessel, S. heterolobus was altogether absent from Truk, whereas this baitfish was the chief component both in Ponape and Palau. As for the availability of baitfish in these areas, the tentative conclusion drawn at this point is that neither Ponape nor Truk would be able to support a skipjack tuna fishery of more than a few vessels. Palau has greater potential, since many of the areas with bait are not now being utilized by the existing fleet of 12 vessels serving the Van Camp Company. The observer felt that Palau could support a larger fishery providing other baiting areas are opened up. To do this, however, he thought that it would be necessary to provide navigational aids that would permit safer passage to the outlying bait areas at night. The Palau fishery at present permits only 1-day trips because of weak bait. Improvements are needed in this area to make longer trips possible.

The observer further reiterated the point that their surveys in Truk and Ponape this year did not include the use of drive-in nets for reef species. Since reef species had been extensively used in prewar years in Micronesia, he emphasized that his conclusions were based only on the lift-net trials, and that a survey of reef resources may show additional potential.

As far as skipjack tuna fishing in these areas was concerned, it was found that skipjack tuna schools were generally scarce. Furthermore, those schools chummed were very unresponsive. In 20 days of fishing around Ponape, only 1.3 tons of skipjack tuna were taken. Around Truk, only 2.1 tons were taken in 19 days of fishing. In Palau, 5.5 tons were taken in 16 days.

The poor fishing results were attributable largely to the poor condition of the baitfish. Weak bait precluded going very far to fish for skipjack tuna. Around Truk and Ponape, those skipjack tuna schools encountered responded very poorly to chumming. Around Palau, where the fishing grounds are relatively far from shore, not enough time could be devoted to fishing skipjack tuna because of the bait experiment underway in the lagoon.

The third in this series of surveys is planned for 1976.

F. BLUEFIN TUNA REARING

The following information is summarized from an article appearing in the Kochi Shimbun dated January 19, 1976, provided by Mr. Hisao Sakamoto of the Nansei Regional Fisheries Research Laboratory in Kochi, Japan.

Although the Kochi Prefectural Fisheries Experimental Station was not a part of the multi-agency cooperative program on tuna culture and rearing sponsored by the Japan Fisheries Agency (1971-73), Kochi researchers independently began work on rearing of bluefin tuna at their branch station facility at Komame, Kochi Prefecture. They worked on this project over a 5-year period, 1970-75, independent of financial support from the national government. The reason given for having undertaken this work was as follows: Yellowtail culture in Japan is considered a leading aquacultural success. Between 1960 and 1970, the production of cultured yellowtail increased thirtyfold. In more recent years, however, the fishery has been plagued with numerous problems including outbreaks of disease (probably related to deteriorating water quality in the culture areas, usually situated in bays and inlets), overproduction, and an alarming decrease in food conversion rate in the cultured fish, all of which have tended to depress the economy of this fishery. Because of these problems with yellowtail, the Kochi Prefectural Fisheries Experimental Station decided to study the feasibility of rearing the highly prized bluefin tuna.

At the outset of the experiments in 1971, the young bluefin tuna, collected by surface trolling and in traps, suffered very high mortality when placed in the rearing enclosures situated in Komame Bay. The mortality was due to injuries incurred when the fish rushed into the sides of the enclosure. After placing the young bluefin tuna in the enclosures, they were fed minced food mixed with antibiotics twice a day. Survival was considerably better among smaller fish; in fish under 300 g, it was extremely good. However, in fish of around 500 g, survival was only around 55%; and in fish larger than 1,000 g, the survival was only 8%. Healthy young fish exhibited a silvery white coloration on their body; weaker fish looked darker and even the body stripes seemed faded.

The Kochi researchers gradually improved rearing techniques and little by little they raised fish to larger sizes. If we look at the results obtained in 1973, it is seen that out of 322 fish placed in the enclosures, 186 had died within the first few days, even before they had begun to feed. Mortality was 58%. Some of the survivors began to feed as early as 3 days after being placed in the enclosures. Between 9 and 12 days, all 136 survivors were feeding and exhibiting growth.

In August 1972, young fish of 0.14 kg were placed in the enclosure. By November 1975 (3 years and 3 months later), the fish had reached a record 50 kg (110 lb). In comparison with this growth rate, a 0.25 kg yellowtail reared from June would reach 1 kg in size by October, 2 kg by March of the following year, and 3.5 kg at the end of 21 months. On the other hand, bluefin tuna started in July at 0. 13 kg reached 1 kg by mid-September; 2.5 kg by November, and in 17 months reached 9 kg in size. During the rearing period, the water temperature in Komame Bay ranged from the maximum 28.8°C in August to a low 15.5°C in February. The bluefin tuna feeds well and exhibits good growth in temperatures ranging between 20.0°-28.5°C.

The bluefin tuna were fed onago(?), mackerel, sardine, and bigeye scad at rates of 16% of body weight in 0.3 kg fish; 10% in 10 kg fish; and 8.5% in 20 kg fish.

In order to test consumer acceptance of reared bluefin, test marketing of the fish showed that the auction prices were similar to those for bluefin tuna taken in the Indian Ocean or in Japanese coastal waters. The quality of the flesh rated high in the markets. During 1973, 1974, and 1975, the average auction price per kilogram was 913 yen and the maximum price was 1,098 yen.

The problem of rearing bluefin tuna in commercial quantities lies in securing sufficient numbers of young fish. Studies are necessary on the resources, their availability, behavior, etc., and methods must be developed for capturing large quantities of young fish. Furthermore, research is necessary to improve survival rate, especially during the early rearing stages. Rather than depend only upon young fish captured in the wild, techniques must be developed to rear larvae hatched from artifically fertilized eggs.

Since bluefin tuna are considerably more sensitive than the yellowtail to water quality, water transparency, and other environmental factors, it is now possible to rear them in only a few selected areas. It appears desirable to set up very large rearing enclosures in deeper, offshore areas where better conditions hold. In fact, this possibility will soon be explored. Because of the favorable results obtained by the Kochi researchers, the Japan Fisheries Agency

has designated the Laboratory to continue this project supported by the Agency's new program, "Development of aquaculture techniques utilizing offshore areas." According to the Director of the Kochi Prefectural Experimental Station, the budget for this project may amount to approximately 100 million yen ($333,330) in 1976 with support from the national government. In 1975, the budget was $33,330. If such support is received, the Kochi researchers hope to work towards commercialization of bluefin rearing. They hope to set up very large enclosures in offshore waters in depths of from 30 to 100 m.

G. THE BLUEFIN TUNA FISHERY IN HOKKAIDO

For many years there has been a small fishery for bluefin tuna along the western coast of Hokkaido. Recently, the fishery has shown signs of expansion. Between 1960 and 1969, the annual total Hokkaido landings ranged between 130 and 500 MT. In 1970, the total incresed slightly to 590 MT, and in 1971 to 677 MT. No data are available for 1972 and 1973, but the 1974 landings amounted to 1,204 MT. There are two areas where bluefin fishing is especially active, one on the northern tip of Hokkaido at Rishiri, where fishing is by longline and pole and line, and the other along the southwestern coast of Hokkaido at Shiribeshi, where bluefin are taken by traps. It is reported that since last year, longline fishing effort has increased at Rishiri and bluefin catches have increased correspondingly. Fish larger than those taken previously have started to enter the catches. Of further interest is the fact that fish with very ripe ovaries have been taken in Hokkaido off Kamuinai in July. One ripe fish was rather small, weighing only 53 kg (147 cm). The gonad weight was measured at 2,710 g, and the gonad index calculated at 8.5. Spawning fish are generally larger than 80 kg. Ripe fish are taken off Taiwan in April-May, and these fish are 175-210 cm in length. Thus, this relatively small fish with ripe ovaries, taken off Hokkaido, is of special interest.

Although the catches at Shiribeshi and Rishiri are relatively small, the bluefin tuna is a high-priced fish and the earnings are good. For example, at Shiribeshi in 1974, a single trap was reported to have grossed 200 million yen ($666,670). The 1971 gross earnings for the Hokkaido landings of 667 MT were reported at 600 million yen (approx. $1.7 million). More recent figures are unavailable.

The fishing season for bluefin tuna along the Japanese coast is from summer to winter. Spawning apparently takes place in the vicinity of Taiwan from April to June. The fish appear off Sanriku (northeastern Honshu) in summer, when purse seiners actively fish this species.

The migratory route of the bluefin tuna into Hokkaido waters is not yet clear. However, the fish begin appearing in July and migrate northward along the Tsushima Current. The northward movement appears to end around October, after which they apparently turn southward. During the period of northward migration the fishing peaks in August. At that time the fish appear relatively close to shore where traps are effective. Fishing peaks again around December during the southward migration. The fish tend to migrate farther off the coast during the southward movement.

The fish taken off Rishiri and Shiribeshi differ considerably in size. The modal sizes of the fish in kg) taken in the two areas are roughly as follows:

Shiribeshi: 1969: 3 kg and 10 kg modes, latter dominant; 90% of fish under 15 kg; no fish larger than 115 kg.

1970: 6 kg, 10 kg, and 20 kg modes; 90% of fish under 25 kg; 1 fish larger than 115 kg.

1971: 5 kg, 12 kg, 23 kg, and 35 kg modes; 90% of fish under 40 kg; 7 fish larger than 115 kg.

1972: 6 kg (dominant), 12 kg, 27 kg, 33 kg modes; 90% of fish under 55 kg; 26 fish larger than 115 kg.

1973: 0.5-1.2 kg (30-37 cm) fish most abundant; smaller modes at 6 kg, and 15 kg; 90% of fish under 20 kg; 26 fish larger than 115 kg.

1974: 4 kg fish most abundant; smaller mode at 12 kg; 90% of fish under 15 kg; 31 fish larger than 115 kg.

The annual sample sizes above ranged from 15,511 fish in 1972 to 73,002 fish in 1974.

Rishiri: 1969: 7 kg, 15 kg, 30 kg modes; 90% of fish smaller than 40 cm; no fish larger than 115 kg.

1970: Largest mode at 27 kg; smaller modes at 15 kg and 45 kg; 90% of fish smaller than 60 kg; 4 fish larger than 115 kg.

1971: A single large mode at around 45 kg; 90% of fish under 75 kg; 25 fish larger than 115 kg.

1972: A single large mode around 60 kg; 90% of fish under 95 kg; 13 fish larger than 115 kg.

1973: A single large mode at around 80 kg; 90% of fish smaller than 100 kg; 20 fish larger than 115 kg.

1974: A single large mode at around 90 kg; 90% of fish smaller than around 115 kg; 144 fish larger than 115 kg.

The sample sizes above ranged from 545 fish in 1969 to 2,484 fish in 1971.

It is seen from the above that there is a progression in modal sizes from 1 year to the next at both areas. The fish sizes are generally larger at Rishiri, where they are taken by longline and pole-and-line fishing.

Hokkaido researchers have estimated the ages of bluefin tuna by the weight-frequency distributions, as follows:

1 year old, 2 kg; 2 years old, 7 kg; 3 years old, 16 kg; 4 years old, 30 kg; 5 years old, 48 kg; 6 years old, 67 kg; 7 years old, 90 kg; and 8 years old, 115 kg.

H. ANTARCTIC KRILL

JAMARC has continued to explore the krill resources in the Antarctic, and has chartered the Taiyo Fishing Company's Capetown-based stern trawler, the No. 82 Taiyo Maru, 3,500 tons, to explore the krill resources off Queen Maud Land. The cruise began in November 1975 and was scheduled to end in March 1976. As of February 15, JAMARC officials reported that the vessel had already taken 1,700 MT and that the ship would catch its capacity in about 10 days. The catch rate was reported at around 40 MT per day.

A previous charter cruise was made in October 1974-March 1975 period by the 1,500-ton No. 11 Daishin Maru. Using a slightly smaller trawl, the vessel took 1,079 MT (gross earnings approx. $606,000); her best catch was around 25.7 MT per day. Thus, this year's results are considerably better.

JAMARC officials are of the opinion that catching krill is no longer a problem. However, the problem of product utilization still remains. Thus far, little progress has been made in this vitally important area. How the krill is to be utilized will determine whether or not present catches are cost-effective in consideration of the long distances to the fishing grounds, high cost of fuel, and other operational requirements.

It is interesting to note that the Nippon Suisan Company has fielded its 3,600-ton stern trawler, Aso Maru, for the second year in a row. This vessel was reported to be making equally good catches and had about 2,600 MT on board as of mid-February.

The great international interest in the krill resources is apparent from the fact that there were, in addition to the two Japanese trawlers, three trawlers from the Soviet Union, one from Poland, one from Chile, and two from West Germany. The West German trawlers were said to be using Montevideo as their base of operation and hosting observers from France and England.

In terms of processing the krill, it was found best to boil it before freezing. On last year's cruise, some krill were experimentally processed on board the No. 11 Daishin Maru as flakes, pressed cake, and dried products. When compared to similar products made ashore, it appeared that these ship-processed products were superior. Further work in this area is being done on the present charter cruise.

I. LIST OF PERSONS CONTACTED DURING TRIP

Far Seas Fisheries Research Laboratory, 1000 Orido, Shimizu

Dr. Y. Fukuda, Director
Dr. Satoshi Mito, Chief, Research Planning and Liaison Office
Dr. Shoji Ueyanagi, Chief, Division of Pelagic Resources
Mr. Koichi Hisada, Division of Pelagic Resources
Mr. Misao Honma, do.
Dr. Shoji Kikawa, do.
Mr. Susumu Kume, do.
Dr. Shou Morita, do.
Mr. Yasuo Morita, do.
Mr. Yasuo Nishikawa, do.
Dr. Chiomi Shingu, do.
Mr. Toshio Shiohama, do.
Mr. Jiro Suzuki, do.
Dr. Tamotsu Yonemori do.
Dr. Ichiro Yamanaka, Chief, Division of Oceanography
Mr. Jiro Morita, Division of Oceanography
Mr. Hajime Yamanaka, do.
Mr. Mori Yukinawa, do.

Tokai University Faculty of Marine Science and Technology, 1000 Orido, Shimizu

Dr. Motoo Inoue, Professor
Dr. Mitsuo Iwashita, do.
Dr. Sigeru Motoda, do.

Tohoku Regional Fisheries Research Laboratory, Shiogama-shi, Miyagi, Japan

Dr. Shigekatsu Sato, Director
Dr. Rikiichi Ishida, Chief, Division of Resources
Dr. Kohei Kasahara, Section Chief, Division of Resources
Mr. Anraku, Division of Resources
Mr. Masahiro Asano, do.
Mr. Naganuma, do.
Mr. Tamotsu Tanaka, do.
Mr. Masakazu Yao, do.
Dr. Tatsuo Yusa, Division of Aquaculture
Dr. and Mrs. Odate (Saury Research)

Federation of Japan Tuna Fisheries Co-operative Associations, 22-3 2-chome Kudankita, Chiyoda-ku, Tokyo

Mr. Shoichi Masuda, President
Mr. Hirosaku Koda, Executive Director, also Vice-Chairman, Japan Tuna Trading Co., Ltd.
Mr. Shiro Yoshizaki, Executive Director
Mr. Shojiro Shimura, Director, Guidance Division
Mr. Mikio Inamori, Chief, Guidance Section, Guidance Division
Mr. Asao Nagamine, Chief, Section of International Affairs
Mr. Suzuki

Japan Marine Fishery Resource Research Center (JAMARC), Godo Kaikan Building, 3-4 Kioicho, Chiyoda-ku, Tokyo

Mr. Kazuo Yasufuku, President
Mr. Kyo Yui, Executive Manager
Mr. Joichi Fujita, Director, Research Division
Mr. Minoru Iida, Chief, Planning Section
Mr. Tadashi Inada, Division of Developmental Research
Mr. Suehiro Machida, do.
Mr. Ryoji Saito, do.

Sanyo Hydrographic Survey Co., 23-7 Shimbashi 5, Minato-ku, Tokyo

Mr. Shigeo Hikosaka, President

Asuka Manufacturing Co., Ltd., 1-chome, Togoshi, Shinagawa-ku, Tokyo

Mr. Y. Kato, President

University of Tokyo, Faculty of Fisheries, Hongo, Tokyo

Dr. Isao Hanyu, Professor
Dr. Robert Izumo, Graduate Student

Universal Marine Consultant Co., Ltd. (UNIMAC), Fuji Building 5-3 1-chome, Yaesu, Chuo-ku, Tokyo

Mr. Masayasu Kato, Executive Managing Director

Institute of Sea Spheres, Takaishi 832-96, Kawasaki-shi, Kanagawa Prefecture

Mr. Hiroyo Koami, Director

Iwatani & Co., Ltd., 7-1 Hatchobori, 2-chome, Chuo-ku, Tokyo

Mr. Teruhiko Yamashita, Deputy Manager, Tokyo Foreign Trade Department
Mr. Shu Furukawa

Bumble Bee Seafoods, Castle & Cooke East Asia, Ltd., Tomihisa Building 5th Floor, 10 Nihonbashi Honcho 3-chome, Chuo-ku, Tokyo

Mr. Y. Munechika, Manager
Mr. Yoichi Horiuchi
Mr. Masahiko Shimada

Japan Fisheries Agency, 1-2-1 Kasumigaseki, Chiyoda-ku, Tokyo

Mr. Teruo Sasaki, Deputy Director General
Mr. Yukio Onda, Chief, Department of Research and Development
Mr. Mutsuya Onda, Chief, Research Division
Dr. Akira Suda, Counsellor, Department of Research
Mr. Koya Mimura, Division of Research

American Embassy, APO San Francisco, California 96503

Mr. Y. Nasaka, Assistant to Regional Fisheries Attache
Ms. Martha A. DeWitt
Ms. Ellen Sasaki

Overseas Fishery Cooperation Foundation, 9-13 Akasaka 1, Minato-ku Tokyo

Mr. Kisaburo Honda, Director, Business Department

Japan Marine Products Photo Materials Association, 601-5-17-1 Hyakunincho, Shinjuku-ku, Tokyo

Mr. Naomi Yoshikawa, Managing Director (Planning and Production)
Mr. Miyoshi

Okinawa Prefectural Fisheries Experimental Station, Itoman, Okinawa

Mr. Akinosuke Tomori, Biologist

Kanagawa Prefectural Fisheries Experimental Station, Jogashima, Miura-shi, Misaki, Kanagawa Prefecture

Mr. Eiji Hanamoto, Biologist

Hokkaido University Faculty of Fisheries 3-chome, Minato-machi, Hakodate 040

Mr. Shoji Saito, Professor

Hokkaido Ritsu Chuo Suisan Shikenjo, 238 Hamanakacho, Yoichi, Hokkaido

Mr. Takashi Yorita, Biologist

NHK, 2-Jinnan, Shibuya-ku, Tokyo

Mr. Yoshio Fukumuro, Director, NHK Eigyo Sokyoku

Nihon Keibi Hosho K.K., 1-7-2 Nishi-shimbashi, Minato-ku (Toranomon Takagi Building), Tokyo

Mr. Norio Chiba, Director, Business Department

Kitasato University, Sanriku-machi, Kesen-gun, Iwate Prefecture 022-01

Dr. Kazuo Fujino, Professor

Southwest Fisheries Center Administrative Report No. 6H, 1976

MAY 10 1977

FISHING SKIPJACK TUNA WITH NORTHERN ANCHOVY IN HAWAIIAN WATERS, JULY 20-22, 1976

Richard N. Uchida[1]

August 1976

---

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

BAIT DISTRIBUTION

The *Pacific Trojan* arrived at Kewalo Basin, Honolulu, at 1500 h on July 19, 1976 and started distributing the northern anchovy, *Engraulis mordax*, soon thereafter to the boats fishing for skipjack tuna, *Katsuwonus pelamis*, or aku boats, as they are called locally, according to a schedule established by drawing lots among the captains. The total amounts received by each of the nine boats that eventually picked up anchovy are shown in the report from Mr. Stanley D. Smith to the Director, Honolulu Laboratory, dated July 23, 1976. The first two boats that picked up bait fared better than the remaining boats. Some captains, who received bait after the second boat was loaded, complained about the "light" buckets of anchovy they received. One in particular estimated that his boat actually received only one-half of what was supposedly loaded on his boat because of the use of a "light" bucket of bait during transfer. Among the 12 Oahu-based aku boats that were originally scheduled to pick up anchovy, only 9 eventually showed up for the bait. After the second boat was loaded, one captain refused the anchovy after learning that the number of buckets of bait to be distributed would be reduced to 20 buckets. The other two simply decided to pass up the anchovy and continue fishing with nehu, *Stolephorus purpureus*, the locally available baitfish.

VESSELS SELECTED FOR OBSERVATION

Industry was strongly in favor of splitting the imported anchovy evenly among the 12 aku boats rather than follow a prescribed plan in which four vessels, selected on the basis of their past performance, would receive a minimum of two full loads of anchovy for field testing. Despite the abandonment of the prescribed plan, the Honolulu Laboratory was able to place observers on five aku boats to collect field data. Of the five boats that participated, three were among the top producers in recent years. Industry argued, and we agreed, that for this initial shipment it would be highly desirable to give as many of the vessels as possible a chance to use anchovy for fishing so that each may decide, on its own, whether future shipments would be desirable.

OBSERVATIONS AT SEA AND INTERVIEWS

The five observers collected data from a total of eight trips on which fishing was attempted with anchovy. For each school, the observers recorded the time of sighting, the start of chumming, and the start and end of fishing. They estimated the amount of bait used per school, counted the number of men that actually fished, recorded the species caught, estimated the average size of the fish in the school from a small sample selected at random, and noted the reason for abandoning a school after chumming it unsuccessfully or after having successfully fished it.

To obtain information from those boats that did not have observers aboard, interviews were held with the boat captains as the boats returned from a day's fishing with anchovy. Among the data collected through interviews were the number of schools chummed during the day, the number of schools successfully fished, amount of bait used for the trip, the species of fish caught, the estimated amount caught, and a personal appraisal of the effectiveness of anchovy in stopping a school and also in holding a school at the stern for effective fishing.

FISHING RESULTS

During the eight trips by the five aku boats with observers, a total of 35 schools were sighted of which 21 were chummed with anchovy and 1 was chummed with a combination of nehu and anchovy. Table 1, which gives the results of those schools that were chummed and also those that were successfully fished, shows the amount of time each school was chummed and the time spent fishing it, the species and amount of bait used, the catch in pounds, and the reason for abandoning the school.

Unfortunately, the data collected are insufficient for any kind of meaningful statistical analysis. In general, the boats that fished with anchovy did very poorly compared to those that fished with a mixture of nehu-anchovy and all nehu. Data in Table 1 reveal that of 21 schools chummed with anchovy, only 7 or 33% were successfully

fished whereas the usual rate of success with nehu is about 50%. With 55 buckets of anchovy used to produce a catch (all species) of 12,583 lb, the catch per bucket of anchovy amounted to 229 lb. The average catch from those schools that yielded fish amounted to 1,798 lb, but based on all schools chummed including those with zero catches, the catch per school amounted to only 600 lb.

By way of a crude comparison, the total catches produced by the fleet, the number of trips involved, and the catch per trip for the period July 20-22 were segregated by type of bait in Table 2. For all boats using only anchovy, the total catch reached 25,874 lb with catch per trip amounting to 1,990 lb on 13 trips. There were three trips with anchovy-nehu used for fishing and these appeared to be quite productive--the catch totaled 19,854 lb and averaged 6,618 lb per trip. Those boats that used only nehu produced 25,518 lb on five trips or 5,104 lb per trip.

Several reasons have been heard for the poor showing of anchovy. These are:

1. "Season" aku, those fish ranging from 15 to 22 lb and which annually constitute the bulk of the catch, were noticeably scarce. The cannery records for the period July 20-22 show that small fish predominated in the catch--6.1% of the landings were extra-small aku (less than 4 lb), 69.7% were small aku (4-8 lb), 1.0% was medium aku (8-15 lb), and only 23.2% were large fish (more than 15 lb). Therefore, most of the fishing with anchovy was on schools of small aku.

2. Because anchovy are larger than nehu, the count or number of individual fish per bucket was considerably less than the number of individuals in a bucket of nehu. Likewise, in chumming, whereas only a few pieces of anchovy can actually be held in each handful or netful to be cast into the water, with nehu considerably more individuals can be held in each handful or netful. The result is that an aku school being chummed with anchovy consumes the few pieces quickly then sounds. With nehu as chum, hundreds of individual fish are cast into the water thus keeping the aku feeding longer at the surface.

3. Some of the anchovy were too large and tended to sound when cast into the water, taking the aku school down with them. On one boat, for example, aku were observed feeding on the larger anchovy several feet below the surface.

4. A mixture of nehu and anchovy may work well if nehu is used to bring the school close to the stern of the boat and anchovy used to hold it there.

Anchovy are strong and survive rough seas, handling, and low oxygen quite well. These desirable characteristics will permit the boats to venture quite far from Kewalo Basin. At present, because of heavy nehu mortalities, many captains are unwilling to risk a trip that would take them far from Pearl Harbor and Kaneohe, the two most productive baiting grounds in the Hawaiian Islands.

Table 1.--Results of fishing with anchovy and anchovy-nehu by five aku boats in the Hawaiian skipjack tuna fishing fleet, July 20-22, 1976.

Time per school		Bait used		Skipjack	Yellowfin				Reason school
Chumming	Fishing	Species	Amount	tuna	tuna	Mahimahi	Others	Total	abandoned
Min	Min		Bkt.	Lb	Lb	Lb	Lb	Lb	
29	--	Anchovy	0.75	--	--	--	--	--	Sounded
15	--	Anchovy	0.75	--	--	--	--	--	Sounded
37	--	Anchovy	0.75	--	--	--	--	--	Sounded
11	--	Anchovy	0.75	--	--	--	--	--	No response
10	--	Anchovy	0.75	--	--	--	--	--	Large yellowfin
3	98	Anchovy	28.00	5,460	654	95	--	6,209	Sounded
45	--	Anchovy	5.00	--	--	--	--	--	No response
8	8	Anchovy	5.00	233	--	--	--	233	Biting stopped
6	5	Anchovy	3.00	18	--	--	--	18	Biting stopped
5	--	Anchovy	0.20	--	--	--	--	--	No response
1	--	Anchovy	0.10	--	--	--	--	--	No response
8	--	Anchovy	0.20	--	--	--	--	--	Sounded
44	--	Anchovy	0.10	--	--	--	--	--	No response
5	--	Anchovy	0.10	--	--	--	--	--	No response
180	25	Anchovy	6.00	1,357	--	--	--	1,357	Biting stopped
1	2	Anchovy	2.00	--	--	399	--	399	Biting stopped
1	11	Anchovy	1.00	--	--	24	--	24	Biting stopped
1	98	Anchovy	11.00	4,343	--	--	--	4,343	No bait left
93	--	Anchovy	3.00	--	--	--	--	--	No response
90	--	Anchovy	3.00	--	--	--	--	--	No response
28	--	Anchovy	4.00	--	--	--	--	--	No response
17	557	Anchovy-nehu	[1]6.00 [2]24.00	15,227	--	--	177	15,404	No bait left

[1]Anchovy

[2]Nehu

Table 2.--Results of fishing with anchovy, anchovy-nehu, and nehu by some of the Hawaiian skipjack tuna fishing boats, July 20-22, 1976.

Type of bait used	Catch	Trips	Catch per trip
	Lb	No.	Lb
Anchovy	25,874	13	1,990
Anchovy-nehu	19,854	3	6,618
Nehu	25,518	5	5,104

[1]All species including 656 lb of yellowfin tuna, 177 lb of kawakawa, and 494 lb of mahimahi.

COUNTRY STATEMENT - U.S.A.

1. FISHERIES ADMINISTRATION

The primary functions of the National Marine Fisheries Service (NMFS) are divided among four major components: Resource Research, Resource Utilization, Resource Management, each headed by an Associate Director, and International Fisheries, headed by an Assistant Director. Under each of the four major components are varying numbers of field units. In addition, the field structure consists of five Regional Offices, each headed by a Regional Director.

In 1975, 10 ships of the National Oceanic and Atmospheric Administration (NOAA) fleet carried out seagoing survey and research tasks of NMFS. This fleet of larger vessels is managed by the National Ocean Survey's (NOS) Office of Fleet Operations (OFO). Several NMFS stations and laboratories also operate small- and medium-sized research vessels not managed by NOS. The 10 ships in the NOAA fleet include the Miller Freeman and John N. Cobb based in Seattle, Washington, David Starr Jordan based in San Diego, California, and the Townsend Cromwell based in Honolulu, Hawaii.

2. PLANNING

In recognition of the tremendous demands being made on the living marine resources of the contiguous waters of the United States and its territories, and in anticipation of the potential increased future demands on those resources, NMFS and NOAA prepared a discussion paper in 1975 entitled "Fisheries Management Under Extended Jurisdiction: A Study of Principles and Policies." This document contributed to the policy framework to the legislation that was being considered by Congress and resulted in the passage of P.L. 94-265, The Fishery Conservation and Management Act of 1976, in early 1976. This law will provide new management authority to greatly improve the opportunities for conservation of recreational and commercial fishery stocks out to 200 nautical miles of the United States and U.S. territorial coasts. In anticipation of the passage of this law the Director of NMFS formed a task force to review organization management in NMFS and to propose changes in the organization and in management processes that will help meet the demands that will be created by extended jurisdiction.

NMFS, in cooperation with State governments, is developing plans aimed at rehabilitating U.S. marine fisheries which are suffering from the effects of heavy fishing and environmental changes. Known as the National Fisheries Plan, its preparation was recommended by the President's National Advisory Committee on Oceans and Atmosphere. A task force has drafted an outline of the plan which describes the present problems facing U.S. fisheries and discusses a series of major issues of primary concern to our national goals in fisheries and related activities.

3. MARINE RESOURCES

3.1 Resource surveying, experimental and exploratory fishing, location of new fishing grounds

The field research work in NMFS is primarily carried out by the variou laboratories in the seven regional fisheries research centers under the Office of Resource Research. In the northeastern U.S., NMFS laboratories in collaboration with other members of the International Commission for the Northwest Atlantic Fisheries (ICNAF) intensively monitored the production and dispersal of larval sea herring, particularly in the Georges Bank-Nantucket Shoals areas. The status of the total resource under harvest in the northwest Atlantic south of Nova Scotia was investigated and summaries of these studies provided major inputs to the management discussions within ICNAF.

The continental slope of the northeastern U.S. was surveyed and information was obtained on the size of the red crab population, their distribution and on their size and sex composition. This information is critical in predicting the availability and for monitoring the developing New England red crab fishery.

Surveys are being conducted in the north central Gulf of Mexico to assess the vast groundfish resource and to determine the amount of groundfish discarded by the Gulf shrimp industry. Assessment of the groundfish resources from Seward in the Gulf of Alaska to Unalaska Bay in the Aleutians was completed in 1975. The assessment indicated that the Kodiak Island and Sanak to Unalaska Bay areas held the best potential for U.S. fishermen.

In 1975 the Townsend Cromwell, presently assigned to the Honolulu Laboratory of the Southwest Fisheries Center (SWFC) completed a preliminary survey of the Northwestern Hawaiian Islands. This preliminary cruise is part of a proposed cooperative survey and assessment of the marine resources of the Northwestern Hawaiian Islands to investigate the terrestrial, nearshore, slope, and pelagic resources of the area and their interrelationships.

3.2 Fisheries biology (including methodology and techniques), studies on age determination, tagging, population dynamics

An otolith workshop attended by 21 scientists from various fisheries research organizations from around the world was held in early 1976 at the Scripps Institution of Oceanography and at the SWFC, La Jolla, California. The agenda of the workshop included presentation of papers relatin to problems of incremental growth in otoliths of larval and adult marine and freshwater fishes. An important aspect of the workshop was the opportunity to examine otolith samples from various species of fish and to exchange information on the interpretation of readings among the participants.

A workshop on the population dynamics of the North Pacific albacore was held at the Honolulu Laboratory, SWFC, in December 1975. The workshop was part of an informal agreement between the SWFC and the Far Seas Fisheries Research Laboratory (FSFRL), Shimizu, Japan, to promote and accelerate cooperative North Pacific albacore research. Participants included scientists from NMFS, FSFRL, California Department of Fish and Game, Oregon Department of Fish and Wildlife, Washington Department of Fisheries, and the Pacific Marine Fisheries Commission. Based on standard analyses of catch, effort, and size composition statistics the workshop tentatively ascertained that the maximum sustainable annual yield of the North Pacific albacore stock was in the neighborhood of 115,000-125,000 MT (metric tons).

The Inter-American Tropical Tuna Commission (IATTC) continued to give considerable emphasis to tagging studies. Greater emphasis was given to tagging yellowfin tuna because this species is much more heavily exploited than skipjack tuna in the areas of recent heavy fishing. In 1974, 8,670 yellowfin tuna were tagged; 186 of these were recovered in 1974 and 122 were recovered in 1975. During the same period 48 skipjack tuna were tagged, with no recoveries.

In an integrated approach to fishery management the NMFS Middle Atlantic Coastal Fisheries Center (MACFC) established a biometrics unit in 1975. Using data from various sources including commercial landings and recreational creel surveys the unit developed yield models of the important middle Atlantic fisheries for summer flounder and butterfish, and modeling of the fisheries for scup and surf clam has begun.

3.3 Fisheries oceanographic studies

Some significant accomplishments in fisheries oceanography in 1975 included the development of an index that relates the effect of wind on ocean surface convergence/divergence. Oregon State University scientists used this material along with previously developed upwelling index time series and applied it to a stock-recruitment model of the Pacific mackerel fishery. The model predicts nearly 80% of the variance in recruitment.

Ultrasonic tracking of albacore concurrent with oceanographic measurements by the La Jolla Laboratory, SWFC, demonstrated that oceanographic conditions play an important role in the concentration and movement of albacore in U.S. coastal waters. Temperature fronts caused by upwelling markedly influenced the local concentration of albacore. Albacore tended to concentrate in the vicinity of these fronts, presumably to feed, and moved away from the immediate area when the upwelling-caused fronts dissipated.

Experiments recently conducted at the NMFS Honolulu Laboratory on captive skipjack tuna, Katsuwonus pelamis, have provided crucial new information on the temperature and dissolved oxygen requirements of this species. If these experimental laboratory results apply to skipjack tuna in the open ocean, they may account for many of the peculiar features of their geographic distribution, and explain why skipjack tuna are seldom

seen in the open ocean even though they appear to be relatively abundant in many areas. These experiments suggest that the actual habitat of adult skipjack tuna in the tropics is the upper thermocline and not the surface mixed layer, as has generally been thought; and that in the eastern tropical Pacific Ocean, and probably in other oceans, certain areas are too warm and oxygen-poor to support this species after they have grown beyond the juvenile or adolescent stage.

The IATTC is continuing work on relating thermal infrared data from satellites to fish catch data. Statistically significant associations were found in a comparison of scanning radiometer (SR) and fish catch. SR has a ground resolution of 10 km and is being gradually superseded by the very high resolution radiometer (VHRR) which has a ground resolution of about 1 km. IATTC work during 1975 was devoted to comparing the quality and utility of VHRR and SR data with that of ocean color data obtained from the earth resources technology satellite (ERTS-1).

3.4 Management laws and regulations, control of pollution

Analysis of the natural production of sockeye salmon in the Naknek and Ugashik Lakes systems of Bristol Bay, Alaska provided revised estimates of adult escapements to each lake system. These escapement figures have direct application to forecasting sockeye salmon returns in Bristol Bay. Also being evaluated is a method of using scale characters to differentiate the Alaska and Asia components of the Japanese high-seas catches of chinook salmon. Estimates by time and area of Japanese mother ship catches of Alaskan sockeye salmon were used to negotiate protection for the 1975 run from high-seas salmon fisheries. This information on interception of U.S.-Canada salmon by Japanese fisheries was compiled for bilateral discussions in early 1976.

Drawing on the results of various analyses a package of conservation recommendations on the major fishery resources of the northeastern Pacific and eastern Bering Sea was developed. These recommendations were utilized by the U.S. in bilateral discussions with the Soviet Union and Poland which resulted in agreements that, for the first time, placed some degree of control over the fisheries of those nations in coastal waters of the United States.

The long-term NMFS objectives of environmental and ecological research are to determine the factors influencing the production of living marine organisms and to obtain baseline data to evaluate the ecological impact of man-induced and natural alterations. Studies are conducted also on the cycling of pollutants through food chains and their effects on marine ecosystems and organisms. Research continued on the relation between petroleum oil and aquatic organisms at the Northwest Fisheries Center (NWFC) installations at Seattle, Washington, and Auke Bay, Alaska. The MACFC established a National Registry of Marine Pathology, which provides reference service for clinical, illustrative, and published materials on diseases of marine and estuarine vertebrates and invertebrates.

3.5 Research programs and institutions

The National Sea Grant Program is administered by the National Oceanic and Atmospheric Administration (NOAA). As of June 1976, ten select colleges and universities have been designated Sea Grant Colleges. The Secretary of Commerce may confer Sea Grant College status on institutions in recognition of its excellence in its marine program. The Sea Grant institutions have highly individual programs serving diverse regions of the country in programs of applied research, education, and advisory service in the marine field.

4. AQUACULTURE

4.1 Intensive and extensive culture techniques--increase in yields

Research supported in the Aquaculture Program of NMFS is aimed at making commercial production of selected species economically feasible in order to encourage the private sector to invest in aquacultural ventures. In addition, research is centered around the improvement of natural stocks for recreational and commercial fishermen. In 1975 work continued on such species as Pacific salmon, penaeid shrimp, blue crabs, and mollusks (oysters, clams, and scallops).

Research on salmon at the Northwest Fisheries Center included development of technology to restore depressed salmon stocks by the release of juvenile salmon produced by new hatchery methods at the Auke Bay, Alaska, Laboratory. Pilot demonstration projects resulted in the production of 35,000 adult salmon (100 MT) in 1975. The number of fish returning per spawner was from 5 to 15 times greater than natural recruitment.

In a molluscan aquaculture program that was reestablished in 1975 at the Milford, Connecticut Laboratory of the MACFC, important programs will include the prophylaxis and treatment of diseases of larvae and juveniles of shellfish species produced in hatchery systems; genetic research on shellfish to develop strains suitable for hatchery use; determining the feasibility of replacing living foods with partially or wholly synthetic foods to satisfy the nutritional requirements of mollusks; and developing laboratory techniques to spawn, rear, and maintain commercial and potentially valuable marine mollusks.

At the Gulf Coastal Fisheries Center (GCFC), Galveston, Texas, in collaboration with scientists at Texas A&M University, shrimp studies continued to help solve problems inhibiting the growth of commercial shrimp farming. Accomplishments included the maturation and spawning of the shrimp, *Penaeus stylirostris* that had been overwintered in raceways before their return to the ponds; maturation and spawnning of specimens in the laboratory; development of portable raceway systems with temperature controls; and construction of new filtration equipment for waste removal and water recycling.

Pilot farm operations conducted cooperatively by the Hawaii Division of Fish and Game (HDFG) and industry for the past several years have resulted in the development of a fledgling Macrobrachium rosenbergii aquaculture industry in Hawaii. In a cooperative arrangement with prawn farmers, HDFG has been providing 2,700,000 juvenile prawns to nine independent prawn farmers who are rearing prawns commercially in a total of about 11.3 ha. (28 acres) of ponds. Annual production was expected to reach about 39,000 kg (85,000 lb) in 1975.

In the State of Washington methods of collecting oyster seed from local oyster beds have been developed to such a stage wherein the State's oyster industry now obtains 80% of its seed requirement domestically and is no longer dependent on importation of seed stock from Japan.

4.2 Feeding, feedstuff

Studies on the nutritional requirements of juvenile blue crabs maintained in artificial seawater were carried out at the Southeast Utilization Research Center. These studies included evaluations on the effect of growth rates caused by different levels of dietary proteins and amino acid supplements. Also effects of increased levels of dietary carotene, background light, and dietary cadmium on survival, growth, and physiology of the blue crabs were investigated.

Components and byproducts of underutilized species, fishery wastes, and other sources were evaluated for use as fish feeds at the Pacific Utilization Research Center.

Studies related to the use of carotenoid pigments from crustacea continued. It was determined earlier that carotenoid pigments impart a desirable red coloration to salmonid flesh, enhancing their marketability. A process to extract carotenoid pigments from crustacea and crustacean wastes was developed. In a study of the use of single cell protein (SCP) derived from yeast as a substitute feed for conventional pen-reared salmonid feed, it was found that substitution of SCP for up to 50% of the protein did not adversely affect the growth rate.

5. INFRASTRUCTURE

A new shipping method to transport live dungeness crabs over relatively long distances has been tested successfully by the NMFS laboratories at Seattle, Washington. This new method may make possible the sale of new varieties of shellfish to consumers far from the site of the catch. The new technique involved the use of an 8.2 m (27 ft) long trailer truck which was lined inside with fiberglass and equipped with a refrigerated seawater circulating system. About 4,800 large dungeness crabs (about 3.6 MT) can be shipped using this system.

6. FISH CAPTURE

6.1 Improvements in materials, design and operations, and introduction of new types of gear

A porpoise/tuna interaction program was a high priority activity of the SWFC in 1975. The program was directed at developing fishing gear to reduce porpoise mortality that occurs during purse seining on yellowfin tuna associated with porpoises in the eastern tropical Pacific. Promising gear innovations have been tested including porpoise safety panels, porpoise aprons, and speed boats to hold the nets open to prevent porpoises from being entangled in the nets and drowning during purse seining operations.

At the NWFC a trawl designed to be selective for pollock and to avoid incidental catches of halibut and crab in the Bering Sea pollock fishery has been tested. The results of the tests are being evaluated and a prototype design is being developed.

6.2 Fish detection, sonar

Preliminary analyses of onsite and satellite data from the LANDSAT (formerly ERTS Satellite) follow-on program indicate that good fish areas may be identified from satellite multispectral scanner data alone. In another development, a towed-array hydroacoustic system developed by the NWFC in cooperation with the Applied Physics Laboratory of the University of Washington has been tested and is being used in the fish stock assessment survey in the northeast Pacific.

7. UTILIZATION

7.1 Improvement in fresh fish handling, distribution, ice supply

Vessels chartered by the New England Fisheries Development Program demonstrated improved on-vessel holding techniques for trawl-caught industrial fish. Fish held in chilled seawater appeared to be superior in quality to those held in conventional iced storage. Based on this initial finding, a herring transport vessel was converted to accommodate bulk holding in chilled seawater. The vessel's holding tank held 56.7 MT (125,000 lb) and in holding experiments maintained herring catches in food-grade condition for up to 60 hours. Present methods allow a holding time of only 5 to 6 hours.

7.2 Product development, new processing methods and equipment

The Texas A&M University, with assistance frmom the Southeast Utilization Center (SEUC), established a pilot minced fish processing plant at Corpus Christi, Texas. The research aimed at the technical feasibility of producing blocks of minced flesh from groundfish species in the Gulf of Mexico, which culminated in the establishment of the pilot plant, represents a milestone in NMFS efforts to increase use of Gulf groundfish.

In an economic study conducted for the New England Fisheries Development Program, it was indicated that a viable squid fishery off the New England coast could add over $600,000 a year to the economy of the region. Squid is presently one of the marine organisms underused by Americans. Of the approximately 31,752 MT (70 million pounds) of squid taken in northeast U.S. waters by foreign and U.S. boats in 1973, only about 1,588 MT (3.5 million pounds) were landed by U.S. boats. Most of the squid landed by U.S. fishermen in this region is taken incidentally while trawling for cod, flounders, haddock, and other fish.

7.3 Research activities and institutions

NMFS issued the First Interim Report of a study on trace elements in fish and shellfish which included data on nine elements in 106 species. When completed this study will provide data on baseline levels for 15 trace elements on over 200 species of U.S. fish and shellfish of significant commercial and recreational interests, and will represent the most comprehensive survey of trace elements in fish and shellfish.

Sea Grant chemists at the Berkeley campus of the University of California have devised a straightforward and uncomplicated procedure that is a hundred times more sensitive than any previous method for detecting the presence in shellfish of saxitoxin. Saxitoxin is the paralytic shellfish poison sometimes associated with the so-called "red tide" blooms on the west coast. The new technique could provide a more scientific approach to the problem of shellfish poison than seasonal closings now in effect.

8. FINANCING THE INDUSTRY

8.1 Government aid to the industry including subsidies

The Financial Assistance Division administers four activities: the Fishing Vessel Obligation Guarantee Program; Fishing Vessel Capital Construction Fund; Fisheries Loan Fund; and, the Fishermen's Guaranty Fund. These programs are aimed at making the harvesting segment of the fishing industry more efficient and competitive by assisting industry in financing investments in vessels and gear. The Fishermen's Guaranty Fund indemnifies against financial losses of U.S. vessles seized by foreign nations. Guaranteed financings in 1975 had an average maturity of 13.5 years and the interest rate averaged 8.74%. Outstanding guarantees and pending applications at the end of 1975 totaled $41 million.

9. STATISTICS

Efforts to improve cooperative State/Federal statistics programs continued in 1975. Most of the Atlantic and Gulf Coast states now cooperatively collect commercial fishing data with NMFS. A few states such as Florida and Texas also process the data for publication, a task which was formerly handled by NMFS. Several noncoastal states presently collect

and furnish data on their own inland fisheries. To eliminate certain duplication of data collection effort from fish processing firms, Washington State will take over almost the entire task formerly done by NMFS. And finally, there has been progress in developing a coastwide fisheries data system with California, Oregon, and Washington.

October 12, 1976

The Pacific Tuna Development Foundation contract specified that the vessel Mary Elizabeth, in conjunction with the Apollo and the Zapata Pathfinder, carry out exploratory fishing for a minimum of 80 days in the area delineated by the following coordinates: 20°S and 170°W; 10°S and 170°W; 10°S and 180°; 20°N and 180°; 20°N and 155°E; 30°N and 155°E; 30°N and 127°E; 7°N and 127°E; 0° and 132°E; 11°S and 151°E; 20°S and 151°E. (See attachment 1 for specifics of the contract.)

The general goal of the charter was to establish whether or not a viable American purse seine fishery could be established in this area.

Specifications of Mary Elizabeth

The Mary Elizabeth has the following specifications: Length, 194.4 ft; beam, 36.1 ft; depth, 14.8 ft; gross tonnage, 916 tons; fish carrying capacity, 1,100 tons. The ship's tanks and double bottoms have a fuel capacity of 93,446 gal. The fuel consumption per day is rated at 3,600 gal at a cruising speed of 15 knots.

Fishing

The Mary Elizabeth departed Panama on June 30, 1976. Search for fish commenced on July 9 after crossing the boundary of the CYRA (Commission's Yellowfin Regulatory Area) at lat. 8°29'N and long. 121°30'W. On July 22 the vessel entered the contract area at lat. 5°N and long. 177°E. Sightings of porpoise herds or bird flocks averaged less than one per day for the first 7 days after crossing the CYRA. Inclement weather precluded search from July 16 to 20.

Scouting was resumed in the Caroline Islands around Kusaie, Ponape, and Truk Islands. Fair numbers of fish signs were seen but the schools were either not large enough (<5 tons) or moving too fast for seining. On July 28, on the northeastern end of Condor Reef,[1] we made our first set on a boiling school of mixed yellowfin and skipjack tunas estimated at 300 tons. The set was unsuccessful, as were sets No. 2 (est. 25 tons), No. 3 (est. 40 tons), No. 4 (est. 60 tons), and No. 5 (est. 10 tons), all of which were made on breezing tuna schools sighted on the southward leg toward New Guinea.

At lat. 0° and long. 140°E, we made our first set on a school associated with drifting log, which resulted in a catch of 15 tons. Three other log sets (sets 7-9), made further south, produced only 9 tons of tuna. Set No. 10, made off New Guinea at lat. 2°S and long. 142°E on a breezing, mixed school of large yellowfin and small skipjack tunas, estimated at 25 tons, was again unsuccessful.

We then proceeded north to concentrate our fishing efforts on log-associated schools. An area with a large number of drifting logs was located between

---

[1]Caution when seining. Fish is closely associated with the edge of the bank. Currents have been reported to be swift at times.

lat. 1°N and 2°N, long. 138° to 139°E. During the succeeding days from August 13 to 21, nine log sets were made, and these resulted in a total catch of 124 tons. On August 21, we departed the area for Guam to refuel.

Search was again resumed at lat. 5°N and long. 140°E heading southward towards the log area. Set No. 20, conducted on a log-associated school at lat. 1°N and 138°E, resulted in a catch of 5 tons. On September 1, we departed this area because of increasingly unfavorable weather and proceeded southeastward to around New Ireland. At the southern end of New Ireland we encountered very rough seas. We then headed north, making passage through St. Georges channel toward the area outside of Rabaul, New Britain. At lat. 4°S and long. 150°E, two sets were made, one a log set and the other on an estimated 5 tons of breezing skipjack tuna. Only the log set was successful, with a catch of 6 tons. As fish signs were poor, we continued running northward. Poor weather at lat. 2°N and long. 151°E on September 12 compelled us to head south and west to around New Ireland and New Britain. Poor search conditions forced us to alter our course and to run northward through the Vitiaz strait between New Britain and New Guinea. Fishing resumed between lat. 1° and 2°S and long. 140° and 141°E. Forty-five tons of tuna were caught on three log sets. Fish signs were plentiful, but an excessive number of logs and debris discouraged us from making additional sets as fish were seen breezing rapidly along from log to log. On September 23 we left the log area to fish toward the southeast. Two sets on skipjack boilers were made at lat. 1°N and long. 151°E. Only one was successful in catching 2 tons of skipjack tuna. The rest of the run towards American Samoa was uneventful. The fishing contract was terminated on October 5.

The tonnage and size breakdown of tuna unloaded at Van Camp, American Samoa were as follows:

Yellowfin tuna under 7.5 lb	52.9 tons
Yellowfin tuna over 7.5 lb	28.6
Skipjack tuna under 4.0 lb	55.5
Skipjack tuna 4.0 to 5.0 lb	31.5
Skipjack tuna over 5.0 lb	47.2
Total	215.7 tons

Catch data by area

Area	No. days in area	No. of sets	No. successful sets	No. of log sets	No. of schoolfish sets	Estimated catch (ton) Yellowfin	Estimated catch (ton) Skipjack	Catch/set (ton)
1976								
Aug.-Sept. 2°N-4°S 138°-147°E	36	18	15	17	1	89	109	11.0
July 22-31 8°-3°N 177°W-147°E	11	5	0	0	5	0	0	0.0
Sept. 4-17, 27-28 0°-6°S 148°-173°E	15	4	2	1	3	3	5	2.0

The following observations are covered by subject:

A. Search

B. Seining operation

C. School-fish

D. Logs

E. Marine mammals

F. Physical characteristics

G. Summary

H. Acknowledgment

A. Search

Search was conducted with two 20X binoculars mounted on the deck of the bridge. Scan range was estimated to be 6 miles on either side of the vessel traveling at an average scouting speed of 14-15 knots. All bird flocks and associated fish schools sighted were evaluated at a distance prior to making contact with them. This versatility resulted in only schools with good surface indications to be actively pursued. Consequently, more fish schools were sighted than were actively pursued or fished. Also, a general tendency toward the latter period of the cruise was to pursue only bird flocks and fish schools associated with logs. Thus, areas with logs were more intensively searched than others. Sixty-two scouting days resulted from 80 days spent in the charter area. Thirty-six days were spent in the log area from lat. 2°N to 4°S and long. 138° to 147°E, 11 days between lat. 3° and 8°N, long. 147°E and 177°W, and 15 days between 0° and 6° S, long. 148° and 173°E. No scouting was possible on 18 days because of adverse weather or because the ship was shifting from one area to another.

B. Seining operation

The net used during the charter cruise was modified from the net used in the eastern Pacific tuna fishery by increasing the fishing depth to 240 m (20 strips). It had a length of 1,600 m. This modified net was comparable in dimensions to those presently used by the Japanese tuna purse seiners (attachment 2).

The net performed very well during fishing operations with the exception of only one instance when the "bunch line" got caught on the cork line, resulting in a 12-ft tear in the net. This incidence was attributed to improper stacking of the net following the previous set. The corks lagged behind the net during retrieval indicating an excess of corks for the net.

During the pursing operation, the purse seine and "hammer plate" were pounded to prevent fish from escaping under the vessel. Whether this pounding was successful in containing the fish could not be ascertained. All sets were completed in 5 to 6 minutes from the time the skiff was released to the time the vessel came up to the skiff. The net was completely pursed in an average of 37 minutes for the 27 sets. Total time from start of set to resumption of search averaged 1.8 hours for the "water-haul" sets.

C. School-fish - Jumpers, breezers, and boilers (not associated with logs)

Most of the schools fished were fast moving and erratic in their behavior, thus making them difficult to set on. Several passes were made around each school prior to seining in order to determine whether or not the school was seinable. Sets were conducted on schools when they appeared on the surface as boilers. Eight sets were made on school-fish between 1100 and 1800 but only one set was successful in catching 2 tons of tuna.

Three schools escaped under the net before the vessel reached the skiff. Three others escaped by running out of the open ends before the set could be completed. We were unable to determine how the fish escaped from the other two sets. Generally, the fish managed to escape from the net within 5 minutes of the start of set.

D. Logs

Few logs were encountered between lat. 8° and 3°N, long. 147°E. Sightings of logs increased considerably toward the south between lat. 2°N and 4°S, long. 138° and 147°E, numbering into several hundreds per day. The greatest singular concentration of logs was sighted on August 29 at lat. 1°36'N, long. 139°30'E (see photograph). This log jam was estimated to be 1 mile long and 50 ft wide, oriented along a northeast to southwest eddy.

In general, logs of all kinds and sizes, from the largest measuring 50 ft to the smallest twigs and debris, were accompanied by fish community with the potential of attracting tuna. The most common fish associated with drift objects was the triggerfish (family Balistidae). Sharks, mahimahi, yellowtail, opelu, and frigate mackerel (*Auxis thazard*), were intermittently caught in log sets. The presence of tuna near a log was never too obvious. During the day only a few jumpers were seen in close proximity to the log. Breezing fish were often observed at some distance from the log, at times approaching the log and then moving off again. Schools generally returned to the log just before dark, as indicated by an increase in activity of jumpers around the log. This is in contrast to Japanese findings by remote sonar sensors that the greatest concentrations occur during noon.

When fishing in areas with large numbers of logs, the largest ones were lashed together and others were brought aboard. The intent was to concentrate the tuna under a single drifting object rather than have them under many scattered ones. As logs were towed behind the skiff, even briefly, we noticed that tunas always surfaced in the wake. Sometimes, a boiling school developed in the wake of a towed log. The log with the best fish signs was selected and marked with a light buoy (25 w, 12 v) and followed during the night. A set was made before sunrise, in darkness, around the light.

Eighteen sets were made around logs and 16 of these were successful in catching an estimated total of 204 tons of tuna. Species composition was 45% yellowfin tuna and 55% skipjack tuna. Two daybreak sets resulted in only one being successful in catching 3 tons of skipjack tuna. Fifty-five percent (113 tons) of the total catch was caught around two logs as follows: Seventy-five tons were caught in three sets over a 4-day period around the very same log. Thirty-eight tons were caught in two sets on consecutive days around a bamboo bush. It is interesting to note that the productive log as well as the bamboo bush were both vertically oriented in the water, the former extending some 30 ft below the surface, and the latter extending its roots down 6 ft. Although it has not been confirmed, we believe that the Apollo may also have fished around this same bamboo bush. The catches suggest strongly that vertically oriented drift objects have better tuna-attracting qualities than those objects that float horizontally on the surface.

E. Marine mammals

Porpoise.--A total of 20 porpoise herds was encountered within the contract area. The largest contained approximately 500 porpoises. Ten contained less than 50 animals. No tuna were observed to be associated with the porpoise except in one instance when it appeared that there may have been some. The possible association in this one case was debatable since the porpoise were located astern of a baitboat actively fishing tuna. Pursuit of the porpoise did not prove any fish to be present.

Dolphins.--Two bottlenose dolphin herds were sighted but no tunas were observed to be associated with them.

Whales.--One set (No. 3) was conducted on an estimated 40-ton breezing tuna school associated with two sei whales (identification not positive). The set was unsuccessful as the whales led the fish out of the open end of the net. The set had been intentionally made to exclude the whales from the set.

F. Physical characteristics

Comparison of catches made on nighttime sets around logs ("night-log sets") in areas of deep mixed layer (>100 m) with catches made on school-fish sets in areas of shallow thermocline (27-40 m) indicate that the former was much more productive. It appears that fishing at night around a log-associated school is far more important than fishing in areas of shallow thermocline. On the other hand, since only two sets were made around logs during daylight hours, the results are inconclusive. However, only one of the two daylight sets was successful.

G. Summary

1. Few logs were encountered in waters north of lat. 3°N, long. 147°E, and southeast of long. 148°E on the run toward American Samoa.

2. Considerable quantities of logs were sighted between lat. 2°N and 4°S, long. 147° and 138°E.

3. The majority of tuna schools sighted were estimated to contain less than 20 tons of fish. Five schools were estimated between 25 and 80 tons, and three were in excess of 200 tons.

4. "Night-log" sets were far more successful than "day school-fish" sets. "Day-log" sets could not be evaluated due to insufficient data. The "night-log" relationship was more significant than that imposed by the deep mixed layer.

5. Areas with isolated logs, where the fish-to-log association could be determined, were significantly more productive than areas with excessive numbers of logs.

6. "Beeper" and sonar instrumentation may increase catch rates substantially during log associated purse seining.

H. Acknowledgment

Appreciation is expressed to Captain Darryl Doiron, Navigator Bob Newton, Chief Engineer Al Simonetti, and the crew of the *Mary Elizabeth* for their cooperation in helping me get my job done.

Attachment No. 2

Vessel	Area used	Size of net
Nippon Maru	Eastern Pacific and West Africa (U.S.-type seiner)	110 m deep x 1,025 m long or 118 m deep x 1,350 m long
Hayabusa Maru	North of Papua New Guinea	220 m deep x 1,600 m long
No. 58 Tokiwa Maru	North of Papua New Guinea	250 m deep x 1,960 m long
No. 55 Hakuryu Maru	Japan coastal waters for skipjack and yellowfin tunas	150 m deep x 1,500 m long or 220 m deep x 1,500 m long
Wakaba Maru	do.	220 m deep x 1,500 m long
No. 23 Taikei Maru	do.	200 m deep x 1,500 m long
No. 28 Kohoku Maru	do.	261 m deep x 2,025 m long
No. 85 Seishin Maru (two-boat seining)	do.	350 m deep x 1,700 m long
No. 7 Konpira Maru (two-boat seining)	do.	240 m deep x 2,400 m long

---

From Trip report: Trip to Japan, January 31-February 22, 1975, by Tamio Otsu.

Southwest Fisheries Center Administrative Report No. 9H, 1976

HARVESTING WITH SMOOTHING COSTS

By

Roy Mendelssohn
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96812

DRAFT FOR COMMENTS

November 1976

Revised June 1977

I. INTRODUCTION

Management plans for renewable resources will not be effective unless they reflect both the economic realities faced by the fishermen and also the vagaries of stock growth. Recent research on the effect of stochastic environmental factors on stock growth, such as currents, thermal isoclines or wind (talks given at the Tuna Conference, Lake Arrowhead, CA, September 1976) suggests that deterministic models will not suffice to manage these resources. When stock growth varies in a probabilistic fashion, deterministic concepts such as "maximum sustained yield" lose meaning.

Fortunately, the mathematics exists to determine optimal policies for stochastic harvesting models (see Jacquette 1972, 1974; Reed 1974, 1975; Mendelssohn and Sobel 1977). The most complete treatment is in Mendelssohn and Sobel (1977), and the purpose of this paper is to extend their results to include costs due to fluctuations in harvest size, called smoothing costs.

For stochastic versions of many of the standard production models, with linear (discounted) costs, an optimal policy in each period t is described by a "base stock size" x_t^o. If the stock size at the beginning of the period is greater than x_t^o, then it is optimal to harvest to x_t^o. Otherwise it is optimal not to harvest. This policy is summarized in Table 1.

Stock size at beginning of period	Optimal harvest size	Stock size at end of period
$x > x_t^o$	$x - x_t^o$	x_t^o
$x \leq x_t^o$	0	x

As the number of periods in the planning horizon tends to infinity, the sequence of x_t^o's tends to a single base stock size x^o, which describes an optimal policy in each period in the infinite horizon model.

It is curious that a similar idea of managing for stock size rather than catch size when growth is stochastic has arisen from the practical experience of several people involved in fisheries research (see Gulland and Boerema 1973 or Radovich 1975). Managing for stock size probably implies that an independent estimate of stock size is available, (which is true for many coastal and demersal fisheries) and will probably delineate where the results we present will be useful.

Let us follow what might happen when following a base stock policy over an infinite planning horizon. Stock size each year is being kept as close to x^o as possible. However, catch size is fluctuating, the amount of fluctuation depending on the variances of the random elements and also on how much the random elements affect the growth of the stock. Downward fluctuations in the harvest may cause economic hardship in the fishery due to insufficient allowable catch to insure everyone a reasonable "profit." Upward fluctuations in the catch may cause the fishermen to "gear up," which will find them in debt in later periods when the catch quota is lowered. The problem is to manage around the base stock size in a manner that reflects the costs due to fluctuations in catch, which we call smoothing costs.

Suppose there is a cost (real or subjective) to an increase in the allowable catch, given by γ for each unit of increase. Similarly, suppose there is a cost ε for each unit of decrease in the catch size between periods. Let z_t be the catch in period t and z_{t-1} the catch in period t-1. Then the net benefit of z_t is:

$$\begin{cases} p \cdot z_t - \varepsilon \cdot (z_{t-1} - z_t) & z_t < z_{t+1} \\ p \cdot z_t & z_t = z_{t-1} \\ p \cdot z_t - \gamma \cdot (z_t - z_{t-1}) & z_t \geq z_{t-1} \end{cases} \tag{1.1}$$

In the literature on inventory and production management, cost structures such as equation (1.1) are analyzed under titles like "Production models with smoothing costs." The similarities between harvesting models and inventory models has been noted elsewhere (Mendelssohn and Sobel 1977), and the results presented here can be seen to be "mirror images" of results in Beckmann (1961) and Sobel (1969, 1971).

Section II formally describes the model to be analyzed. Section III describes the results for a finite planning horizon. Section IV extends these results to an infinite planning horizon. Section V discusses possible extensions of the results. Only the theorems are presented in the main body of the paper. The proofs can be found in the appendix.

For a real-valued function f that maps a subset of $\mathbb{R}$ into $\mathbb{R}$, f^1 denotes the derivative of the function. If a real-valued function h maps a subset of $\mathbb{R}^2$ into $\mathbb{R}$, $h^{[1]}$ denotes the partial derivative with respect to the first argument, and $h^{[2]}$ the partial derivative with respect to the second argument.

II. THE MODEL

The resource is being managed for a planning horizon of T periods, $0 < T \leq \infty$. The periods are subscripted by $t = 1, 2, \ldots, T$ or alternatively by $n = T - t + 1$, the number of periods remaining in the planning horizon. At the beginning of each period t, an initial stock size x_t is observed, a harvest of size z_t is taken during period t, and a stock size y_t is left at the end of the period after harvesting has ceased. The stock size at the beginning of period $t + 1$, x_{t+1}, is a random function of the stock size at the end of period t and an exogenous random variable; i.e.

$$x_{t+1} = s[y_t, D_t]$$

where $s[y_t, D_t]$ is the "transition function" and $D_1, D_2, \ldots, D_T$ are independent, identically distributed random variables, distributed as the generic random variable D. The proofs do not depend on D being a scalar random variable; thus $D_1, D_2, \ldots, D_T$ can be a sequence of independent, identically distributed random vectors, distributed as the generic random vector D. This implies that the transition function is capable of including any number of environment variables.

For each fixed realization of the random variable D_t (denoted by d), $s[\cdot, d]$ is assumed to be concave and continuous. Many of the standard production models satisfy these assumptions. A harvest of $z_t = x - y_t$ produces a return of $G(x - y)$. If z_t is greater than z_{t-1}, there is a cost of $\gamma \cdot (z_t - z_{t-1})$, $\gamma \geq 0$. If z_t is less than z_{t-1}, there is a cost $\varepsilon \cdot (z_{t-1} - z_t)$, $\varepsilon \geq 0$. The total one period return in period t is:

$$\begin{cases} G(z_t) - \gamma \cdot (z_t - z_{t-1}) & z_t > z_{t-1} \\ G(z_t) - \varepsilon \cdot (z_{t-1} - z_t) & z_t < z_{t-1} \\ G(z_t) & z_t = z_{t-1} \end{cases}$$

and this return is discounted by a factor α^{t-1}, $0 < \alpha \leq 1$.

The model as described is a two state model. At the beginning of each period, an initial population size x is observed, and a harvest size z from the previous period also is known. If (x, z) is the observed state in period t, then Beckmann (1961) shows that equation (2.1) can be rewritten as:

$$G(z_t) - e \cdot (z - z_t) - c \cdot |z_t - z| \tag{2.2a}$$

$$= G(x - y_t) - e \cdot \left(z - (x - y_t)\right) - c \cdot |x - y_t - z| \tag{2.2b}$$

where $e = \frac{(\gamma + \varepsilon)}{2}$ and $c = \frac{(\gamma - \varepsilon)}{2}$. The dynamic optimization problem is to choose a feasible sequence $\{y_t\}$ that:

$$\text{maximizes } E\left\{\sum_{t=1}^{T}\left[\alpha^{t-1} g(x, y, z)\right]\right\} \tag{2.3}$$

$$\text{subject to } 0 \leq y_t \leq x_t;\ 0 \leq z_t \leq x_t;\ x_{t+1} = s[y_t, D_t]$$

$$x_t, y_t, z_t, \geq 0$$

and $g(\cdot, \cdot, \cdot)$ is given by equation (2.2b). It follows from Sobel (1969) that if an optimal policy exist, it must be the solution to the following system of recursive equations:
(where n = the number of periods remaining, is the subscript).

$$f_o(\cdot,\cdot) \equiv 0 \tag{2.4}$$

$$f_n(x, z) = \sup_{0 \leq y \leq x} \left\{J_n(x, y) - c \cdot |x - y - z| - e \cdot z\right\}$$

where $\quad J_n(x, y) = G(x - y) + \alpha E\left\{f_{n-1}(s[y, d], x - y)\right\}$

To describe an optimal policy, we need to make assumptions about $G(z)$, the immediate return from a harvest of size z. The following assumptions are discussed in Mendelssohn (1976) or Mendelssohn and Sobel (1977):

$$\begin{aligned} &\text{(i) } G(x, y) \text{ is concave and continuous on the set} \\ &\qquad C = \{(x, y): x \in X;\ 0 \le y \le x\} \\ &\text{(ii) } G(\cdot, y) \text{ is nondecreasing} \\ &\text{(iii) } G^{[2]}(\cdot, y) \text{ is nondecreasing} \\ &\text{(iv) } G \text{ is nonnegative (uniformly bounded below) on } C. \end{aligned} \tag{3.1}$$

Further, consider the following two functions:

$$\begin{aligned} y_n^1(x) &= \sup\left\{y: J_n^{[2]}(x, y) \ge -c;\ 0 \le y \le x\right\} \\ y_n^2(x) &= \sup\left\{y: J_n^{[2]}(x, y) \ge c;\ 0 \le y \le x\right\} \end{aligned} \tag{3.2}$$

Let us consider the meanings of these different definitions. $y_n^1(x)$ is a feasible y for each x, such that if the harvest size is increased, it is optimal to increase it to $x - y_n^1(x)$. Similarly, $y_n^2(x)$ is such that if the harvest size decreases, it is optimal to decrease to $x - y_n^2(x)$. It is shown in Mendelssohn (1976), or Mendelssohn and Sobel (1977) that an optimal policy function $A_n(x)$ for the problem with no smoothing costs has the following properties:

$$0 \le \frac{d}{dx} A_n(x) \le 1$$

This leads us to suspect that it might be true that, $0 \le \frac{d}{dx} y_n^i(x) \le 1$ for $i = 1, 2$. Theorem 1 is the main theorem of this paper. It states that this conjecture is correct, and shows how this can be used to describe an optimal policy function.

<u>Theorem 1</u> (a) Let $G(x, y)$, the one period benefit from harvesting, be given by equation (3.1). Then there exists two functions $y_n^1(x)$ and $y_n^2(x)$, defined in equations (3.2) such that the value of an optimal harvesting strategy is given by:

$$f_n(x, z) = \begin{cases} J_n(x, x) - c \cdot z & : x < y_n^2(x) \quad \text{Region I} \\ J_n(x, y_n^2(x)) + c \cdot (x - y_n^2(x) - z) & : x - z < y_n^2(x) \quad \text{II} \\ J_n(x, x - z) & : y_n^2(x) \leq x - z \leq y_n^1(x) \quad \text{III} \\ J_n(x, y_n^1(x)) - c \cdot (x - y_n^1(x) - z) & : x - z > y_n^1(x) \quad \text{IV} \end{cases}$$

an optimal harvesting strategy is given by:

$$A_n(x, z) = \begin{cases} x & : x < y_n^2(x) \quad \text{I} \\ y_n^2(x) & : x - z < y_n^2(x);\ x \geq y_n^2(x) \quad \text{II} \\ x - z & : y_n^2(x) \leq x - z \leq y_n^1(x) \quad \text{III} \\ y_n^1(x) & : x - z > y_n^1(x) \quad \text{IV} \end{cases}$$

(b) Let $A_n(x)$ be the policy function when $\gamma, \varepsilon \equiv 0$. Then, under the assumptions of part (a), the following inequalities are true:

(i) $x - y_n^1(x) \leq x - A_n(x) \leq x - y_n^2(x)$

(ii) $0 \leq A_n^{[1]}(x, z) \leq 1$

(iii) $-1 \leq A_n^{[2]}(x, z) \leq 0$

(iv) $0 \leq y_n^{2\prime}(x) \leq 1$

(v) $0 \leq y_n^{1\prime}(x) \leq 1$

□

Fig. 1 Theorem 1 provides a welter of results at once. Figure 1 summarizes visually an optimal policy. The abscissa is the value of x, the ordinate is the value of z. What is read off the graph is the value of $z_t = x - A_n(x, z)$, by finding the corresponding value on the z-axis. The left-most dotted line shows the limits of the constraint $x_t \geq z_t$. The middle dotted line is the policy $z = x - A_n(x)$.

A second way of summarizing an optimal policy is given in Table 2. The first column considers the value of the remaining stock size if the old harvest were followed. The second column gives the optimal harvest size, and the third column gives the remaining stock size.

Stock size if harvest unchanged	Optimal harvest	Size of remaining stock
$x - z < y_n^2(x);\ x < y_n^2(x)$	0	x
$x - z < y_n^2(x);\ x \geq y_n^2(x)$	$x - y_n^2(x)$	$y_n^2(x)$
$y_n^2(x) \leq x - z \leq y_n^1(x)$	z	x - z
$y_n^1(x) < x - z$	$x - y_n^1(x)$	$y_n^1(x)$

Consider each region. In region I, $J_n^{[2]}(x, x) > -c$. In other words, it would be desirable to decrease the harvest beyond zero. Since this isn't feasible, $A_n(x, z) - x$ is an optimal policy. In region II, either a decrease in harvest size is absolutely necessary, due to the constraint $x \geq z_t$, in which case

$A_n(x, z) = y_n^2(x)$ is optimal, or else at $y_n^2(x)$ the marginal gain from decreasing the harvest size just equals the marginal cost. In region III, the marginal cost of any change in harvest size is greater than the increase in value. In region IV, $y_n^1(x)$ is the point where the marginal increase in value due to an increase in harvest size just equals the marginal change in the cost.

Clearly the choice of c (respectively of γ, ε) influences an optimal policy to a large degree, as the width of region III will depend on these values. In many fisheries contexts, c represents a subjective weighting against undesirable events rather than a true monetary cost. Therefore, care should be used when actually choosing a value for c. For numerical problems, several values of c might be tried, in order to see how sensitive an optimal policy is to changes in c. We conjecture, but have not proven, that the change in an optimal policy is greater when changes are made in small values of c than when changes are made in large values of c. The intuition behind the conjecture is that as smoothing costs first enter the problem, an optimal policy "jumps" to include these costs. But as c gets larger and larger, an optimal policy becomes heavily weighted towards not changing the allowable catch, and therefore changes in the value of c should have little effect on an optimal policy.

IV. INFINITE HORIZON MODEL

In this section, n, the number of periods remaining in the planning horizon, approaches infinity. As in the base stock size policy, it would be convenient if as n approaches infinity, that an optimal policy approach a stationary policy, that is one that doesn't depend on the period. If such limits exist, consider the following five functions:

$$\begin{aligned} A(x, z) &= \lim_{n \to \infty} A_n(x, z) \\ y^1(x) &= \lim_{n \to \infty} y_n^1(x) \\ y^2(x) &= \lim_{n \to \infty} y_n^2(x) \\ f(x, z) &= \lim_{n \to \infty} f_n(x, z) \\ J(x, y) &= \lim_{n \to \infty} J_n(x, y) \end{aligned} \tag{4.1}$$

Theorem 2 states conditions for which these limits exist, and for which the functions described are the functions for the infinite horizon problem.

<u>Theorem 2.</u> (a) Assume $s[\cdot, d]$ is nondecreasing for each fixed value of d. Then:

$$\begin{aligned} y_{n+1}^1(x) &\geq y_n^1(x) \\ y_{n+1}^2(x) &\geq y_n^2(x) \\ A_{n+1}(x, z) &\geq A_n(x, z) \\ f_{n+1}(x, z) &\geq f_n(x, z) \\ J_{n+1}^{[2]}(x, y) &\geq J_n^{[2]}(x, y) \end{aligned}$$

(b) Assume also that c, e are finite and that G(z) is bounded above by a finite number M such that $\lim_{t \to \infty} \alpha^{t-1} M \to 0$. Then there exists functions $A(x, z)$, $y^1(x)$, $y^2(x)$, $f(x, z)$, and $J(x, y)$ defined in equation (4.1) such that an optimal policy for the infinite horizon problem is given by:

$$A(x, z) = \begin{cases} x: x < y^2(x) & \text{Region I} \\ y^2(x): x - z \leq y^2(x);\ x \geq y^2(x) & \text{Region II} \\ x - z: y^2(x) \leq x - z \leq y^1(x) & \text{Region III} \\ y^1(x): y^1(x) \leq x - z & \text{Region IV} \end{cases}$$

the value of an optimal policy is:

$$f(x, z) = \begin{cases} J(x, x) + c \cdot z & \text{Region I} \\ J\left(x, y^2(x)\right) + c \cdot \left(x - y^2(x) - z\right) & \text{Region II} \\ J(x, z) & \text{Region III} \\ J\left(x, y^1(x)\right) - c \cdot \left(x - y^1(x) - z\right) & \text{Region IV} \end{cases}$$

and the following inequalities are valid:

(i) $x - y^1(x) \leq x - A(x) \leq x - y^2(x)$

(ii) $0 \leq A^{[1]}(x, z) \leq 1$

(iii) $-1 \leq A^{[2]}(x, z) \leq 0$

(iv) $0 \leq y^{2'}(x) \leq 1$

(v) $0 \leq y^{1'}(x) < 1$

□

The interpretation of theorem 2 is essentially that of theorem 1, so it will not be repeated. Over an infinite horizon, the problem reduces to one of calculating two functions, $y^1(x)$ and $y^2(x)$, both of which have derivatives bounded between zero and one. Sobel (1971) discusses how to take advantage of similar structure in an optimal policy function in order to efficiently calculate an optimal policy.

V. DISCUSSION AND SUMMARY

We have seen that when smoothing costs are added to a harvesting problem, a three region optimal policy arises. These regions smooth out the fluctuations in the catch while still being concerned about effects to the stock. The exact balance that is achieved will depend on the relative values of the smoothing costs to the "market" value of the harvest.

Certain immediate extensions suggest themselves. $G(z)$ and $s[y, d]$ often are period dependent functions, reflecting perhaps seasonal fluctuations in price or growth. Theorem 1 is valid as stated as long as the assumptions are valid for each G_n and s_n. However, theorem 2 is not necessarily valid as stated in the nonstationary case.

Also, for most fisheries, a more realistic description of smoothing costs assumes that for a certain level of change, there is no smoothing cost, and that the per unit cost decreases as the change begins to get large. That is, some fluctuations are too small to notice, and some are so large that the "damage" has already been done, and the increased cost due to an even larger change is minimal.

In practice, some if not all of the functions will be difficult to estimate. However, experience with and knowledge of a fishery may make it possible for a manager to put approximate bounds on the three regions. Certainly knowing the form of a policy is a step towards obtaining methods to put numbers in that form. It is hoped that this initial effort will stimulate such applied research.

LITERATURE CITED

BECKMAN, M. J.

1961. Production smoothing and inventory control. Oper. Res. 9:456-467.

CLARK, C. W.

1976. Mathematical bioeconomics. John Wiley & Sons, N.Y., 352 p.

DANTZIG, G. B.

1955. Linear programming under uncertainty. Manage. Sci. 1: 157-206.

DENARDO, E. V.

1967. Contraction mappings in the theory underlying dynamic programming. SIAM Rev. 9:165-177.

GULLAND, J. A., and L. K. BOEREMA.

1973. Scientific advice on catch levels. Fish. Bull., U.S. 71:325-335.

IGLEHART, D. L.

1965. Capital accumulation and production for the firm: Optimal dynamic policies. Manage. Sci. 12:193-205.

JACQUETTE, D. L.

1972. A discrete time population control model. Math. Biosci. 15:231-252.

1974. A discrete time population-control model with setup costs. Oper. Res. 22:298-303.

MENDELSSOHN, R.

1976. Optimal harvesting strategies for stochastic populations. Ph.D. Dissertation, Yale University, New Haven, Conn., 98 p.

MENDELSSOHN, R., and M. J. SOBEL.

1977. Optimal harvesting strategies and capital accumulation.

RADOVICH, J.

1975. Application of optimum sustainable yield theory to marine fisheries. In P. M. Roedel (editor), Optimum sustainable yield as a concept in fisheries management. Am. Fish. Soc., Spec. Publ. 9:21-28.

REED, W. J.

1974. A stochastic model for the economic management of a renewable animal resource. Math. Biosci. 22:313-337.

1975. Some stochastic models in animal resource management. Ph.D. Thesis, University of British Columbia, Vancouver.

SOBEL, M. J.

1969. Production smoothing with a stochastic demand I: Finite horizon case. Manage. Sci. 16:195-207.

1971. Production smoothing with stochastic demand II: Infinite horizon case. Manage. Sci. 17:724-735.

APPENDIX

It is convenient to prove lemma 1 and theorem 1 together, and then to prove theorem 2 as an extension of the results of theorem 1. That will be our approach.

Proof of Lemma 1 and Theorem 3

At $n = 1$, the return is $G(x-y) - e \cdot (z-(x-y)) - c \cdot |x-y-z|$ which by the assumptions on G is jointly concave in (x, y, z). From a theorem in Iglehart (1965), which he attributes to A. F. Veinott, Jr. and is a generalization of a theorem due to Dantzig (1955), it follows that $f_1(x, z)$ is concave and (left)-continuous in (x, z).

As an induction hypothesis, assume $f_1, f_2, \ldots, f_{n-1}$ are concave and continuous, and that $f_{n-1}(\cdot, z)$ is nondecreasing and $f_{n-1}(x, \cdot)$ is nonincreasing (which we will prove shortly). This implies that $\alpha E f_{n-1}(s[y, d], x - y)$ is jointly concave in (x, y) and that $G(x - y) - e(z - (x - y) - c \cdot |x - y - z| + \alpha E f_{n-1}(s[y, d], x -$ is jointly concave in (x, y, z). Again, from the theorem in Iglehart, it follows that $f_n(x, z)$ is jointly concave in (x, z).

If the induction hypothesis is true for some n, then an optimal y can be found by taking the partial derivative with respect to y, and making it as close to zero as possible, subject to $0 \leq y \leq x$. Suppose $x - z \geq y_n^1(x)$. Then:

$$J_n^{[2]}(x,\ y_n^1(x)) + c = 0$$

or else $y_n^1(x) \equiv x$. Thus, if the conditions defining region IV are valid, then $y_n^1(x)$ is optimal.

Suppose $x \leq y_n^2(x)$. Then, since $z \geq 0$, $x - z < y_n^2(x)$, so that the harvest must be decreased. Again,

$$J_n^{[2]}(x,\ y_n^2(x)) = 0$$

or else $y_n^2(x) \equiv x$, so that $y_n^2(x)$ is an optimal decision. If $x \geq y_n^2(x)$, and $x - z < y_n^2(x)$, by the same reasoning, $y_n^2(x)$ again is an optimal decision.

Suppose $y_n^2(x) \leq x - z \leq y_n^1(x)$. Then:

$$-c \leq J_n^{[2]}(x,\ x - z) \leq c$$

At $y = x - z$, the derivative is $J_n^{[2]}(x,\ x - z)$. An increase in y will decrease the value, i.e., $J_n^{[2]}(x,\ x - z + \delta) + c \leq J_n^{[2]}(x,\ x - z)$ and $J_n^{[2]}(x,\ x - z - \delta) - c \geq J_n^{[2]}(x,\ x - z)$ for $\delta > 0$, which implies that $x - z$ is an optimal decision. If the theorem is true in period j, then:

$$f_j^{[1]}(x,\ z) = \begin{cases} J_j^{[1]}\left(x,\ y_j^2(x)\right) + c & \text{Region I + II} \\ J_j^{[1]}(x,\ x - z) + \left[J_j^{[2]}(x,\ x - z)\right]^+ & \text{Region III} \\ J_j^{[1]}\left(x,\ y_j^1(x)\right) - c & \text{Region IV} \end{cases}$$

$$f_j^{[2]}(x, z) = \begin{cases} -(e + c) & \text{Region I + II} \\ -J_j^{[2]}(x, x - z) - e & \text{Region III} \\ c - e & \text{Region IV} \end{cases}$$

which proves that $f_n(\cdot, z)$ is nondecreasing and $f_n(x, \cdot)$ is non-increasing.

To see where we are, we have shown that $J_1(x, y) - c \cdot |x - y - z| + e$ is concave in (x, y, z), which implies an optimal policy given in part (a), which implies $f_1(x, z)$ is concave and continuous, and that $f_1(\cdot, z)$ is nondecreasing, $f_1(x, \cdot)$ nonincreasing. Assume this for $f_1, f_2, \ldots, f_{n-1}$. Then $\alpha E f_{n-1}(s[y, d], x - y)$ is jointly concave in (x, y), $J_n(x, y) - c \cdot |x - y - z| + e \cdot z$ is jointly concave in (x, y, z). Again, this implies an optimal policy given by part (a), which in turn implies $f_n(x, z)$ is concave and continuous, $f_n(\cdot, z)$ is nondecreasing and $f_n(x, \cdot)$ is nondecreasing, which are the desired results.

Much of part (b) has already been proven. By the definition of the four regions, in regions I, II, IV $A_n(x, z)$ does not change with z, in region III the change is exactly equal to the change in z. This proves (iii), $-1 \leq A_n^{[2]}(x, z) \leq 0$. Note that claim (ii) implies claim (iv) and (v). To see this, in region III it is already true that $0 \leq A_n^{[1]}(x, z) \leq 1$. If this is true in all other regions, since $A_n(x, z)$ will equal either $y_n^1(x)$ or $y_n^2(x)$ in these regions, (ii) must imply (iv) and (v).

At period 1:

$$f_1^{[1]}(x, z) = \begin{cases} 0 & \text{Region I} \\ 0 & \text{Region II} \\ 0 & \text{Region III} \\ 0 & \text{Region IV} \end{cases}$$

because $f_1^{[1]}(x, z) = G'\left(x - A_1(x, z)\right) + e\,(\pm)\,c + \left[-G'\left(x - A_1(x, z)\right) - e(\mp)c\right]^+ = 0$

and

$$f_1^{[2]}(x, z) - \begin{cases} -(e + c) & \text{Region I} \\ -(e + c) & \text{Region II} \\ -G'\left(x - A_1(x)\right) - e & \text{Region III} \\ c - e & \text{Region IV} \end{cases}$$

Assume for periods 1, 2, ..., n-1 $f_j^{[1]}$ is zero. To show this implies $f_n^{[1]}$ is zero, consider the region II case first.

Then:

$$\begin{aligned} f_n^{[1]}(x, z) = {} & G'\left(x - A_n(x, z)\right) + e + c + \Big[-G'\left(x - A_n(x, z)\right) \\ & - e - c + \alpha E\Big\{f_{n-1}^{[1]}\left(s\left[A_n(x, z), d\right]\right) s^{[1]}[A_n(x, z), d] \\ & - f_{n-1}^{[2]}\left(s[A_n(x, z), d], x - y\right)\Big\}\Big]^+ \\ & + f_{n-1}^{[2]}\left(s[A_n(x, z), d], x - y\right) \\ = {} & \alpha E\Big\{f_{n-1}^{[1]}\left(s[A_n(x, z), d], x - y\right) s^{[1]}[A_n(x, z), d]\Big\} \end{aligned}$$

$= 0$ by the induction hypothesis and similarly for the other regions. Likewise

$$f_n^{[2]}(x, z) = \begin{cases} -(e + c) & \text{I + II} \\ -J_n^{[2]}(x, x - z) - e & \text{III} \\ c - c & \text{IV} \end{cases}$$

Therefore:

$$J_n^{[2]}(x, y) = G'(x-y) - e - \alpha E\left\{f_{n-1}^{[2]}\left(s[y, d], x - y\right)\right\}$$

which is increasing in x. This implies:

$$A_n(x, z) \leq A_n(x', z) \qquad \text{for } x' \geq x.$$

Put the problem in terms of x and the decision $z = x - y$. Then:

$$H^{[2]}(x, z) = G'(z) + e + \alpha E\left\{f_{n-1}^{[2]}\left(s[x - z, d], z\right)\right\}$$

which again is nondecreasing in x. This implies that:

$$x - A_n(x, z) \leq x' - A_n(x', z) \qquad \text{for } x' \geq x.$$

Together the two inequalities imply

$$0 \leq A_n(x', z) - A_n(x, z) \leq x' - x \qquad \text{for } x' > x.$$

which implies $\quad 0 \leq A_n^{[1]}(x, z) \leq 1.$

The final result is that:

$$x - y_n^1(x) \leq x - A_n(x) \leq x - y_n^2(x)$$

or equivalently:

$$y_n^2(x) \leq A_n(x) \leq y_n^1(x).$$

At period n:

$$J_n^{[2]}\left(x, A_n(x)\right) = -G'\left(x - A_n(x)\right) - e + \alpha E\left\{f_{n-1}^{[2]}\left(s[A_n(x), d], x - A_n(x)\right)\right\}$$

Assume as an induction hypothesis that:

$$\alpha E\left\{f_{n-1}^{[2]}\left(s[A_n(x), d], x - A_n(x)\right) - f'_{n-1}\left(s[A_n(x), d]\right)s^{[1]}[A_n(x), d]\right\}$$

$$\leq |c| \qquad \text{(A.1)}$$

where $f_{n-1}(x)$ is the value function without smoothing costs. The inequality implies the result. However, the inequality is trivially true in period one. From the definition of $f_n^{[2]}(x, z)$, the result in period n implies inequality (A.1) for $f_n(x, z)$ which completes the proof.

□

Proof of Theorem 2

We assume the set X of feasible population sizes has a finite least upper bound.

Part (a). For fixed z:

$$f_1^{[1]}(x, z) - f_o^{[1]}(x, z) = f_1^{[1]}(x, z) \geq 0$$

$$f_1^{[2]}(x, z) - f_o^{[2]}(x, z) = f_1^{[2]}(x, z) \leq 0$$

As an induction hypothesis, assume for some n, that:

$$f_n^{[1]}(x, z) \geq f_{n-1}^{[1]}(x, z), \quad f_n^{[2]}(x, z) \leq f_{n-1}^{[2]}(x, z)$$

Then:

$$J_{n+1}^{[2]}(x, y) - J_n^{[2]}(x, y) =$$

$$\alpha E\{(f_n^{[1]}(s[y, d], x - y) - f_{n-1}^{[1]}(s[y, d], x - y))s^{[1]}[y, d]$$

$$- (f_n^{[2]}(s[y, d], x - y) - f_{n-1}^{[2]}(s[y, d], x - y)) \geq 0$$

This implies that:

$$A_n(x, z) \geq A_{n-1}(x, z) \tag{A.6}$$

From the definition of $A_n(x, z)$, $A_{n-1}(x, z)$ given in theorem 1, $A_n(x, z) \geq A_{n-1}(x, z)$ must imply:

$$f_{n+1}^{[1]}(x, z) \geq f_n^{[1]}(x, z)$$

$$f_{n+1}^{[2]}(x, z) \leq f_n^{[2]}(x, z)$$

which completes the induction.

Part (b). We make the further assumption that $0 < \alpha < 1$. We have proven in part (a) that:

$$A_{n+1}(x, z) \geq A_n(x, z)$$

However, since the set X is bounded below by zero and has a finite upper bound by assumption, this implies that $\{A_n(x, z)\}$ approaches a limit $A(x, z)$. Moreover, since the one-period return is finite and bounded,

$$\alpha^{t-1} g(x, y, z) \to 0$$

as $t \to$ infinity, where $g(x, y, z)$ is given by:

$$G(x - y) - c \cdot |x - y - z| + e \cdot z.$$

It follows from Denardo (1967) that $\{f_n\}$ must converge to a limit $f(x, z)$ as n approaches infinity. Since both sequences $\{f_n(x, z)\}$ and $\{A_n(x, z)\}$ converge, of necessity, the sequence $\{J_n(x, y)\}$ must converge to a limit $J(x, y)$.

The stationarity of $J(x, y)$, $f(x, z)$, and $A(x, z)$ and the concavity of $J(x, y)$ and $f(x, z)$ imply that:

$$y_n^1(x) \to y^1(x) \text{ as } \quad n \to \infty$$

$$y_n^2(x) \to y^2(x) \text{ as } \quad n \to \infty$$

which completes the proof of part (b).

$\square$

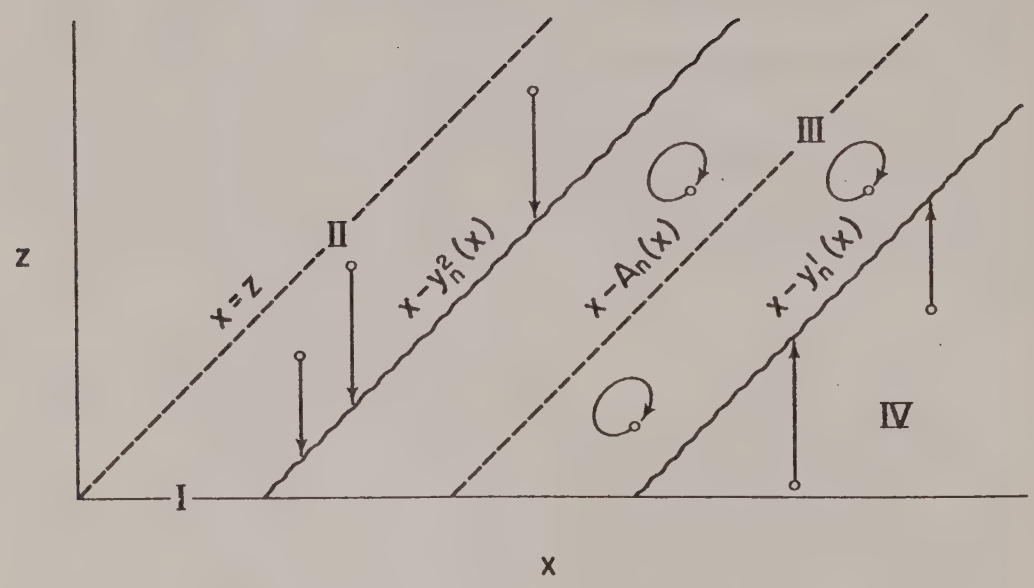


Figure 1.--This figure describes an optimal harvest for period n for a concave return function G(x - y). See text for more details.

COOPERATIVE NORTHWESTERN HAWAIIAN ISLANDS RESOURCE ASSESSMENT PROGRAM

November 1, 1976

COOPERATIVE NORTHWESTERN HAWAIIAN ISLANDS RESOURCE ASSESSMENT PROGRAM

INTRODUCTION

The Northwestern Hawaiian Islands (NWHI), often referred to as the "Leeward Islands," stretch for over a thousand miles northwestward beyond the island of Kauai in the major Hawaiian group. The tiny islands and atolls composing this chain have been worn down to vestiges of their former estate and support only a limited assortment of land animals and plants. The flora is similar to that of a tropical beach with virtually all the plants near the shore with but a few exceptions. Crowding these islands are a rich assortment of marine and shore birds.

There is a great urgency to know a great deal more about the marine resources of these NWHI. The State of Hawaii, pressed with growing demands for assessment and rational utilization of its marine resources, recognizes the vital importance of the sea to its economic growth and has fostered a program of harvesting the marine resources of the waters surrounding the entire Hawaiian chain (Hawaii and the Sea, published by the State of Hawaii, Department of Planning and Economic Development, 1969, 1974).

The NWHI, with the exception of a few islands near the southeastern end of the chain, are virtually untouched by commercial fishing. It would be highly desirable, from the point of view of population dynamics, to investigate an area such as the NWHI where relatively virgin conditions exist. The study would allow a determination of the status of the stock before the effects of fishing mortality sets in. And Honolulu's proximity to the NWHI is advantageous to an intensive investigation at minimal costs.

Another important consideration in undertaking a study of the NWHI is the interrelationship between the marine environment in that area and their inhabitants. Designated a National Wildlife Refuge in 1909, the NWHI, except Midway, is a sanctuary for numerous species of seabirds, Hawaiian monk seals, and sea turtles. However, the boundary of the refuge is a source of attrition between the State of Hawaii, who represents potential user groups and the U.S. Department of the Interior's Fish and Wildlife Service (FWS), who administers the refuge. A study of the marine species utilized as food by the refuge inhabitants should help to obviate the conflict.

Additionally, with the advent of the Fishery Conservation and Management Act of 1976, which prescribed a 200-mile coastal jurisdiction, it becomes imperative that the character of the waters surrounding the NWHI and the extent of the marine resources be fully investigated. Not only will information be required for negotiations with foreign countries, but also for those U.S. fishers who may be looking for new fishing grounds as a result of being displaced from traditional grounds in foreign waters.

The extent of the research proposed is beyond the present capabilities of the staff and facilities of any research agency in Hawaii. Therefore, the National Marine Fisheries Service (NMFS), Southwest Fisheries Center, Honolulu Laboratory, has proposed a cooperative research effort with the State of Hawaii's Division of Fish and Game (HDFG), University of Hawaii Sea Grant, and the FWS. The study will encompass assessment of the terrestrial, nearshore, slope, seamounts, and pelagic resources of the NWHI and the interaction and interrelationship of the various resources as it relates to competition for food and habitat.

OVERVIEW OF PROPOSED PROGRAM

A broad program of research to study the terrestial and marine resources of the NWHI could be structured into the following categories:

1. Nearshore
2. Inner and outer shelves, shelf edge, and upper slope
3. Pelagic
4. Seamounts and offshore banks
5. Hawaiian monk seals and marine turtles
6. Marine birds
7. Interaction and interrelationship of the various resources listed above

The Honolulu Laboratory proposed exploratory fishing surveys of the NWHI over a 5-year period beginning with cruise TC-76-06-73 of the NOAA ship Townsend Cromwell (FRS-43) beginning October 12, 1976. A preliminary proposal of the types of information needed to assess the marine community is as follows:

1. Bottom topography of the areas surrounding the NWHI.
2. Distribution and relative abundance of demersal fish and shellfish on the inner and outer shelves, shelf edge, and upper slope.
3. Distribution and relative abundance of fishes found on seamounts and offshore banks.
4. Species composition, distribution and density of planktonic and macroorganisms including fish, crustaceans, mollusks, corals, and algae.
5. Physical and chemical parameters of the waters surrounding the various islands and seamounts.
6. Distribution and relative abundance of the pelagic fishes with emphasis on tuna and tunalike species.
7. Food, feeding habits, distribution and abundance of marine birds, seals, and green sea turtles.

The Honolulu Laboratory will focus attention on a quantitative fishery assessment and survey of the inner and outer shelves, shelf edge, and upper slope zones, the pelagic zone with emphasis on tuna and tunalike fishes, and resources over submerged seamounts and offshore banks. A basic inventory of the physical and biological characteristics of the waters overlying these zones will also be undertaken.

Study and assessment of the land-associated resources will be the basic responsibility of the FWS. Their investigation will include determination of the magnitude of the marine bird resource in the sanctuary, the energy dynamics of marine birds, and the food and feeding habits of marine birds. The Northwest Fisheries Center in Seattle will undertake life history studies of the Hawaiian monk seal. Studies on the distribution, abundance, feeding habits, and behavior of the green sea turtles will be carried out by the Hawaii Institute of Marine Biology, University of Hawaii (HIMB).

Participation of the HDFG will be directed to the study and assessment of fishery resources of the nearshore zone, which extends from the shoreline, including the splash zone, seaward to a depth of about 20 m.

SAMPLING GEAR

The resource assessment surveys do not constitute a program in gear design; rather, the primary objective of these surveys will be the determination of distribution and relative abundance patterns and to approximate the magnitude of the exploitable stock. It is anticipated, however, that problems in gear design can be considered during subsequent stages of development of a fishery.

For demersal species, the primary gear considered will be fish trawls, traps, pots, and handlines; for pelagic species, such as tunas and tunalike fishes, pole-and-line fishing with live bait and troll gear appear to be the most appropriate sampling gears.

In addition to the gears used to accomplish our primary objectives, other sampling devices will be used to collect data for environmental studies. Acoustic gear will be used to obtain better estimates of the bottom configuration, grab samplers to determine ocean bottom types, midwater trawl, and plankton hauls for micronekton and zooplankton studies, and STD and XBT casts to determine changes within the physical parameters.

DISTRIBUTION OF SAMPLING ACTIVITIES

At present, little is known about the bottom topography of the area; therefore, it is highly desirable to determine initially, the stratum boundaries during the early surveys to select the character that would be most useful for stratifying the sampling activities. Stratification could also be done according to depth ranges, for example, inner shelf (10-20 fathoms or 18-36 m), outer shelf (20-25 fathoms or 36-45 m), shelf edge (25-50 fathoms or 45-90 m), top of the upper slope (50-100 fathoms or 90-180 m), middle of the upper slope (100-150 fathoms or 180-270 m), and bottom of the upper slope (150-200 fathoms or 270-360 m). A diagrammatic sketch is shown in Figure 1.

Fig. 1

Exploratory trawling surveys will be conducted to determine the locations of trawlable grounds. A previous exploratory cruise to the NWHI (cruise 80 of the RV David Starr Jordan) has shown that the 20-600 m depth zones hold the most promise for fishery development. Grab samplers will be used to obtain small samples from the surface layer of the ocean bottom at selected study areas. Ocean bottom types will be categorized as follows: (1) sand, (2) silt, (3) rubble, (4) boulder, (5) live coral, (6) bedrock, (7) sandstone flats, (8) dead coral flats, and (9) others.

Not only the shelf and upper slope area but also the submerged offshore banks and seamounts will be investigated. Larger banks will undoubtedly receive more sampling effort and seamounts will be subjected to briefer surveys.

As more information is gathered on the locations of trawlable grounds, the surveys will be designed so that both random and systematic sampling of known fish concentrations will be conducted day and night. For example, the stock of Naso spp. (Acanthuridae) has been found to be rather substantial during cruise 67 of the RV Townsend Cromwell in the 22-54 m (18-30 fathom) depth range near Nihoa Island. Known concentrations of Naso spp. will be sampled systematically and other areas will be trawled randomly to determine the extent of their distribution and abundance.

Other aspects of the assessment surveys would require the use of traps, pots, and handline gear. From the results of preliminary fishing with these gears, study sites for more intensive sampling will be selected and sampling stations within each study site will be established.

NMFS SAMPLING PROGRAM

DEMERSAL SPECIES

Species groups that are more likely to be encountered and which are of interest to NMFS are as follows: Serranidae (Epinephalus), 1 sp.; Carangidae (Seriola, Carangoides, Caranx), 9 spp.; Lutjanidae (Pristipomoides, Lutjanus, Aprion, Etelis), 6 spp.; and Mullidae (Mulloidichthys, Parupeneus), 6 spp. Fish families of lesser interest are the Holocentridae, Priacanthidae, Cirrhitidae, Pomacentridae, Labridae, Acanthuridae, Pentacerotidae, and Scorpaenidae--about 22 spp.

Crustaceans of interest are shrimp (Heterocarpus, Penaeus), 3 spp.; kona crab (Ranina serrata); lobster (Panulirus) 2 spp.; and white crab (Portunus sanguinolentus).

Specific objectives would be to determine the following:

1. The structure of the fish communities present on the inner and outer shelves, shelf edge, and upper slope zones.
2. Their distribution in time and space.
3. The relative abundance of the exploitable stock of each species present.
4. The yield potential of each species.
5. The feasibility of commercial exploitation of the various species stock.

Sampling for demersal fishes will be carried on in depths ranging from 20 to 400 m, with stratification of the potential fishing grounds into six strata as shown in Figure 1. Fish trawls, traps, and handlines, the principal gears to be used, will be standardized after initial tests have been completed. Preliminary surveys will be conducted with a high-opening, roller-rigged Norwegian fish trawl, with gear modification carried out as necessary. Standard fish traps and traditional handlines will also be used in the surveys.

The exploitation of two demersal fish species--the pelagic armorhead, Pentaceros richardsoni, and alfonsin, Beryx splendens--on the seamounts and offshore banks near the NWHI are now exploited by Japanese and Russian trawlers. Unconfirmed reports indicate that for the armorhead, at least, Russian trawlers harvested about 133,400 MT (metric tons) during an 8-month period in 1969-70. The bulk of the Japanese and Russian catches of armorhead, however, occur outside the U.S. fishery conservation and management zone. Inside the zone, on Hancock seamount, foreign catches of armorhead are unknown. Trawling surveys of seamounts and banks will be conducted to obtain estimates of the exploitable stock.

Occurring in quantities apparently sufficient to support a fishery, two species of shrimp, Heterocarpus spp., have been caught in exploratory deepwater shrimp trapping surveys in Hawaiian waters. In 1973, preliminary surveys showed that Heterocarpus spp. also occur in modest quantities near Necker Island and French Frigate Shoals in the NWHI. Additional shrimp trapping surveys will be necessary in selected areas to determine depth-abundance curves, optimum fishing strategy, and standing biomass.

Also found near French Frigate Shoals were small quantities of the penaeid shrimp, Penaeus marginatus. Additional exploratory surveys with the shrimp trawl will be necessary to determine the locations of commercial concentrations and estimate their distribution and standing biomass.

Other crustaceans of interest for possible exploitation are the spiny lobster, kona crab, and white crab. Trapping operations will be conducted for these species along with fish-trapping surveys. These species, however, will receive less sampling effort if preliminary results indicate that the stocks are too small for commercial exploitation.

BENTHOPELAGIC SPECIES

Benthopelagic species, those that occur both on or near the bottom and in midwater or surface layers, may be present in sizable quantities as results of a preliminary acoustic survey in the summer of 1973 indicated. Schools of unidentified fish, detected on top of the banks and estimated to be at depths of 10-30 m and extending nearly 11 km in one direction, were near the bottom during daylight hours but were observed to move off the bottom and disperse in midwater at night. The high-opening bottom fish trawl will be used in attempts to sample and identify these schools.

At night-light stations, handlines will be used to sample for the presence of the commercially important akule, *Trachurops crumenophthalmus*, and opelu, *Decapterus pinnulatus*. Also, observations will be made near islands and atolls to determine whether night light can be used effectively to attract baitfish in any appreciable quantities. Previous NMFS surveys, which date back to the early 1950's, showed that baitfish are present in small quantities near the shorelines of several islands and atolls; however, their occurrence appears to be sporadic.

PELAGIC SPECIES

In recent years, the NWHI has also received increasing attention from foreign tuna pole-and-line and longline fishing vessels. In the summer of 1974, for example, Japanese pole-and-line vessels reportedly caught 1,350 MT of skipjack and yellowfin tunas from waters near the NWHI. In addition to skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, data collected on previous NMFS research cruises to the North Pacific have shown that in the general vicinity of the NWHI, a number of other tuna and tunalike fishes are present. Among them are bigeye tuna, *Thunnus obesus*, albacore, *T. alalunga*, wahoo, *Acanthocybium solandri*, kawakawa, *Euthynnus affinis*, bonito, *Sarda* sp., and mackerel, *Scomber* sp. Some species of tuna and tunalike fishes apparently are sufficiently abundant seasonally in waters of the NWHI so that they can form the base of a troll fishery which could be conducted in conjunction with bottom fishing.

To assess the pelagic resource, survey vessels will troll during all daylight hours between stations. Furthermore, it is anticipated that commercial fishing boats will be chartered to fish the study area with pole-and-line and troll gear to assess the relative abundance of the various pelagic species in space and time.

SUPPLEMENTARY RESEARCH

It is anticipated that primary aggregation studies conducted in June-September 1976 on cruise 76-05-72 of the RV Townsend Cromwell in Trust Territory waters will be continued not only in the main group of the Hawaiian Islands but also in waters of the NWHI. Anchored floating objects will be placed over various offshore banks, as time permits, during the survey cruises in attempts to concentrate schools of pelagic fishes. Observations on species and numbers aggregated by the floating objects will be made daily while the survey vessel is nearby and examined during the time that the vessel passes through the area to and from port.

Among the most useful characteristics for age and growth determination of fish--at least for fishes of the temperate zone--are the annuli on bony parts such as scales, otoliths, spines, and opercular bones. Attempts to age tropical fishes by examining hard parts and by other conventional means such as length-frequency mode progression analyses have failed because of the absence of well-defined annuli and the presence of protracted spawning periods in some species. In recent years, however, researchers have successfully aged tropical species by examination of daily growth increments in the sagittae of otoliths. Samples of otoliths collected from fishes captured during the survey of the NWHI will be examined by a specially trained team conducting age and growth studies at the Honolulu Laboratory.

COOPERATIVE RESEARCH

Extensive observations of various environmental parameters and collection of a variety of fishes, invertebrates, fish eggs and larvae, and micronekton by plankton hauls and midwater trawls will provide physical data and biological samples which could be examined by cooperating investigators. Although critical examination of some of these biological samples and environmental data may not be done immediately, the opportunity to commence their collection in such a poorly known region should not be ignored.

The nearshore and lagoon areas will be the primary responsibility of the HDFG. The nearshore area includes (1) the splash zone or the land area exposed to spray and under the influence of waves, (2) the inner nearshore zone from the shoreline to a distance of about 6 m seaward, and (3) the outer nearshore zone extending from the outer boundary of the inner nearshore zone to a depth of about 20 m. The inventory of the marine fauna in these areas will be accomplished by conducting fish survey transects with scuba divers. Islands and atolls that would come under investigation include Nihoa, Necker, French Frigate Shoals, Gardner Pinnacles, Maro Reef, Laysan, Lisianski, Pearl and Hermes Reef, and Kure Island. It is anticipated that the HDFG will provide assistance in evaluating the results of each cruise.

Another research proposal is a study of the structure of nearshore reef communities. Preliminary surveys by the HDFG (cruise 76-04-71 of the RV Townsend Cromwell) have indicated that some fish species common to waters of the major Hawaiian group appear to be virtually absent from waters surrounding the NWHI. From an ecological point of view, it would be highly desirable to determine if there is an actual break in the distribution of major species or groups. Cooperating in this project will be the Southwest Fisheries Center's Tiburon Laboratory. Biologists of the Tiburon Laboratory will conduct an ecological study of the nearshore fish community and note changes of species complex throughout the entire Hawaiian chain.

Responsibilities for survey and assessment of land-associated resources lie with the FWS. Their studies will include the determination of a base line magnitude of the marine bird resource in the wildlife refuge, the energy dynamics of marine birds, an inventory of the food consumed, location of major feeding areas, and rate of food consumption. An important part of their research will center on an assessment of the potential effects of commercial and sport fishing upon marine birds. In addition to these studies, the HIMB contemplates a census of adult green sea turtles and studies on their distribution and abundance, daily activities, and types of food consumed.

The FWS Mammal Research Unit in Anchorage, Alaska, also plan to undertake studies of the Hawaiian monk seal in cooperation with personnel of the NMFS, Northwest Fisheries Center, Seattle. Surveys will be made to estimate their abundance, rate of mortality, age composition, sex ratio,food and feeding habits, female recruitment, and tolerance to human disturbance. The effects of proposed fishery harvest within waters of the NWHI will also be evaluated.

The possibility that ciguatera toxin may occur in some species found in the NWHI is most important to the successful marketing of those species. The flesh of a number of fishes is toxic to man. Some are always toxic whereas others may be consumed safely most of the time but suddenly cause grave illness or even death at other times. Poisonous fishes frequently occur among reef dwellers. More than 300 kinds of fishes have been incriminated in ciguatera-type fish poisoning, a poison which affects mostly the nervous reaction with a reversal of hot and cold sensations being common in severe cases. It is anticipated that some species, before they can be market tested, will need to be evaluated for ciguatera toxin.

APPLICATION OF POTENTIAL ACCOMPLISHMENTS

The accumulation of data, their analyses, and final dissemination of the results will greatly increase not only our knowledge of the fishery resources of the NWHI but also our understanding of the refuge inhabitants and their interaction with the marine resources. The

information generated on distributional range, migrations, and seasonal changes in distribution, yield, and age composition will be essential for establishing the policies needed for successful management. Hopefully, the knowledge and understanding gained on the structure and function of insular ecosystems will be useful in assessment of insular resources elsewhere in the Pacific.

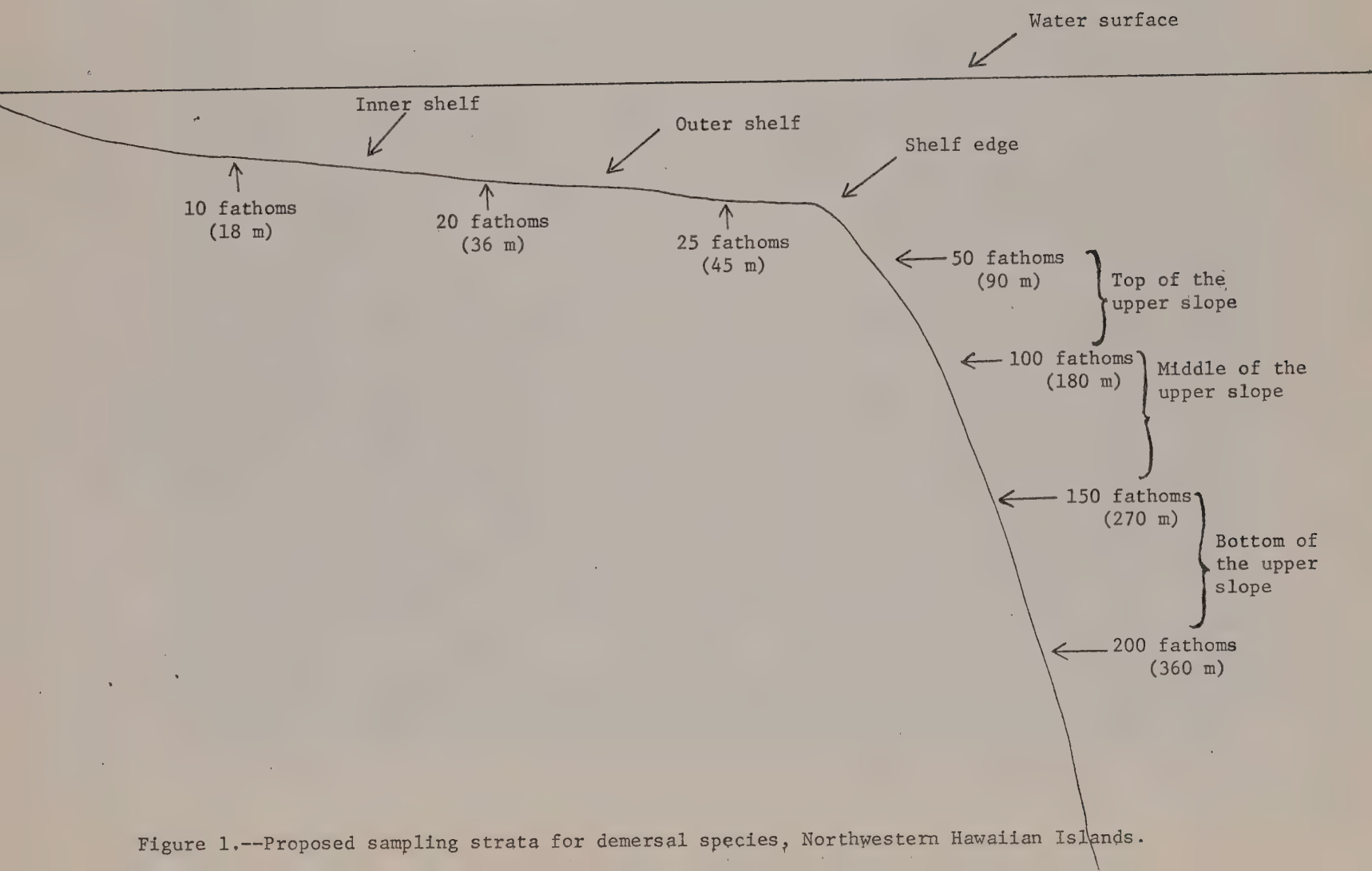
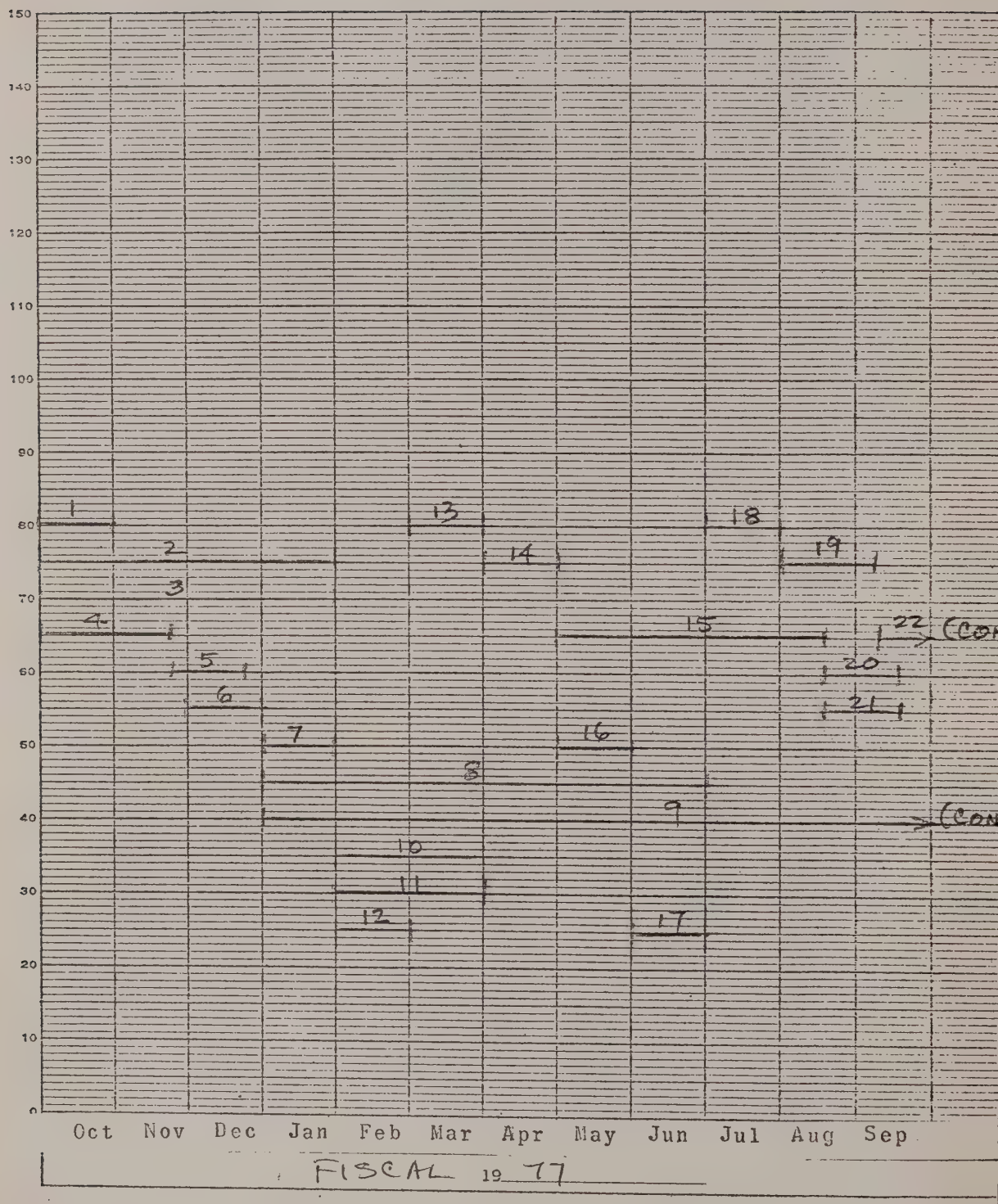


Figure 1.--Proposed sampling strata for demersal species, Northwestern Hawaiian Islands.


150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
FISCAL 19 77

Explanation of PERT chart

1. Finalize program proposal.
2. Preparation of background document of the Northwestern Hawaiian Islands.
3. Preparation of field procedures manual and log forms for field use.
4. Cruise TC-76-06-73. At end of cruise, turn in completed Cruise Report and Press Release.
5. Preparation of Narrative Report for cruise TC-76-06-73, hold post-cruise meeting.
6. Repair all scientific gear and fishing equipment used on cruise TC-76-06-73.
7. Precruise planning for cruise TC-77-03-76, determine cruise strategy, circulate preliminary cruise instructions 90 days prior to start of cruise, accumulate supplies, order gear as necessary.
8. Establish data base management system.
9. Analyses of field data including catches from bottom fish trawl, trolling, plankton and midwater trawls, fish traps, lobster pots, and handline; sample of otoliths collected for aging of tropical fishes; and oceanographic and topographic data. Results to be prepared for publication.
10. Explore contract fishing for pelagic and some demersal fishes using pole-and-line, trolling gear, and handline.
11. Explore ciguatera and market testing of species caught in waters of the Northwestern Hawaiian Islands.
12. Revise Cruise Instructions as necessary, TC-77-03-76.

13. Issue final Cruise Instructions, TC-77-03-76.

14. Prepare all gear and equipment for cruise, TC-77-03-76.

15. Cruise TC-77-03-76. At end of cruise, turn in completed Cruise Report and Press Release.

16. Precruise planning for cruise TC-77-04-77, determine cruise strategy, circulate preliminary cruise instructions 90 days prior to start of cruise, accumulate supplies, order gear as necessary.

17. Revise Cruise Instructions as necessary, TC-77-04-77.

18. Issue final Cruise Instructions, TC-77-04-77.

19. Prepare all gear and equipment for cruise, TC-77-04-77.

20. Preparation of Narrative Report for cruise TC-77-03-76, hold post-cruise meeting.

2. Repair all scientific gear and fishing equipment used on cruise TC-77-03-76.

22. Cruise TC-77-04-77. At end of cruise, turn in completed Cruise Report and Press Release.

Southwest Fisheries Center Administrative Report No. 11H, 1976

DISTRIBUTION AND ABUNDANCE OF SKIPJACK TUNA LARVAE

By

Walter M. Matsumoto

Southwest Fisheries Center
National Marine Fisheries Service, NOAA
Honolulu, HI 96812

November 5, 1976

INTRODUCTION

The distribution of tuna larvae, particularly that of skipjack tuna, has been fairly well documented for the Pacific Ocean, and to a lesser degree for the Indian and Atlantic Oceans. The source of data has been mainly from plankton net tows and although a large number of net tows have been accumulated over the years by various agencies, the collective data suffer from differences in the size of nets, in towing methods, and from inadequate coverage in vital areas of the oceans. Consequently, while the data provide valuable qualitative information, they are not entirely reliable for oceanwide quantitative analyses. It is important, therefore, to examine the status of our knowledge concerning larval skipjack tuna and to point out what needs to be done.

DISTRIBUTION

The distribution of skipjack tuna larvae can be looked at from various aspects: geographically, vertically, environmentally, and seasonally.

(a) Geographic distribution.--We know that skipjack tuna larvae

Fig. 1 are found over extremely wide areas of the oceans. Figure 1 shows the capture sites of skipjack tuna larvae in the Pacific and Indian Oceans as obtained from the literature (Matsumoto 1958; Strasburg 1960; Klawe 1963, 1970, 1971, 1972, 1974; Nakamura and Matsumoto 1967; Ueyanagi 1969; Chen and Tan 1973) and from unpublished data (Southwest Fisheries Center,

Honolulu Laboratory files). The distribution is broad in the central and western Pacific (from 30°-35°N to 35°-40°S) and narrow in the eastern Pacific (from 15°N to 15°-20°S). Both the northern limit of distribution is relatively firm, but the southern limit could be better defined with additional sampling. The distribution in the Indian Ocean is not quite as extensive as in the Pacific, the northern boundary being limited to about 10°-12°N by the Asian Continent. The southern boundary could be modified with further sampling, particularly in the central and eastern sectors.

(b) Vertical distribution.--The vertical distribution of tuna larvae has been studied by various researchers. Matsumoto (1958) speculated that few tuna larvae occurred in waters much deeper than 50 m in the central Pacific, on the basis of simultaneous horizontal triple-net tows made at depths of 0, 50, 100; 0, 100, 200; 0, 150, 300 m. Klawe (1963) found no evidence of tuna larvae in waters deeper than the thermocline (12-48 m) in the eastern Pacific. Strasburg (1960), who used opening and closing nets, found six times more skipjack tuna larvae at the 0-60 m depth than at the 70-130 m depth, and practically none (only one larva) at the 140-200 m depth. He also found that surface tows caught twice as many skipjack tuna larvae as the 0-60 m depth tows. Finally, Ueyanagi (1969) found little difference in the catches of horizontal tows made simultaneously at the surface and at the 20-30 m depth. It is evident from these observations that skipjack tuna larvae are concentrated in waters near the surface, that the occurrence may be uniform to at least 30 m, and that only a small portion is found in depths greater than 60 m.

(c) Distribution relative to thermocline.--The absence of skipjack tuna larvae below the thermocline in the eastern Pacific (Klawe 1963) could be a valid local phenomenon. In the central Pacific, the situation may be quite different. Strasburg (1960), in analyzing the catches of tuna larvae taken in opening- and closing-net tows, showed that while most of the skipjack tuna larvae were found above the thermocline (79 larvae in 6 tows), some were found at greater depths (8 larvae in 3 tows at 70-130 m and 1 larva at 140-200 m). The thermocline depth in the sampling area ranged from 30 to 60 m.

(d) Distribution relative to surface currents.--The broad latitudinal distribution of skipjack tuna larvae in the western Pacific and the narrow distribution in the eastern Pacific (Figure 1) is primarily due to the prevailing surface currents (Matsumoto 1975). In the western part of the ocean, the equatorial currents flow poleward, carrying warm water suitable for skipjack tuna spawning away from the equatorial region and thereby expanding the spawning area. Conversely, in the eastern part of the ocean, cold currents from high latitudes flow toward the equator causing the area of warm water favorable for spawning to be contracted to a relatively narrow band along the equator. The configuration of the warm area in the Pacific is shown by the 24°C isotherms in Figure 1. Differences in the surface current patterns in the Indian Ocean cause the distribution of skipjack tuna larvae there to differ from that in the Pacific Ocean. The distribution in the eastern sector is not narrowed as it is in the Pacific because the short western Australian coast, which terminates at around 35°S, does not extend southward far

enough to effectively funnel the cold polar water northward as the South American Continent does in the Pacific Ocean. The northward extension of the distribution, of course, is restricted by the Asian Continent.

(e) Surface temperature.--The mean 24°C isotherms shown in Figure 1 fairly well define the northern and southern limits of larval skipjack tuna distribution. The isotherms shown represent that of the warmest month in each hemisphere, i.e., northern summer in the north and southern summer in the south. The several points shown outside of the isotherms represent catches made either in colder water or in years when the warm water may have been displaced farther poleward.

Both the minimum and maximum temperatures for larval skipjack tuna occurrence have been found to differ by areas. In the western North Pacific, a summary of surface night tows from 10 cruises of the *Shunyo Maru* (data from Ueyanagi 1969) showed that all except one larva were taken in waters 25°-29°C. The one exception was a larva taken in 30°C water. The most productive tows were in 28°C water, while the lowest temperature in which skipjack larvae were caught was 23.5°C in a subsurface tow. In the central North Pacific (Hawaiian Islands area) a summary of surface night tows from nine cruises of the *Cromwell* (Matsumoto and Skillman, MS[1]) showed that nearly all of the skipjack tuna

---

[1]Matsumoto, W. M., and R. A. Skillman. Synopsis of biological data on skipjack tuna, *Katsuwonus pelamis* (Linnaeus). Manuscript in preparation. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

larvae taken had been from waters 23° to 26°C, and the most productive tows in terms of occurrence and number of larvae were in 25° and 24°C, water, respectively. The lowest temperature in which skipjack tuna larvae were caught was 22.1°C.

(f) Seasonal distribution.--It is generally known that skipjack tuna spawn the year round in tropical waters, and seasonally in subtropical waters. The seasonal shifts in the distribution of skipjack larvae are clearly seen in the western North Pacific (Figures 2a and 2b). Seasonal spawning occurs in Hawaiian waters also, but it is not evident from the figures because the longer spawning period there, March or April to October or November, extends beyond the 6-month period used to designate the warm and cold seasons in the figures (the figures were reproduced mainly from Ueyanagi 1969). Seasonal shifts in the distribution of larvae is not evident in the western South Pacific (west of 140°W) because of insufficient sampling south of 25°S in the southern summer (Figure 2a). Many of the larval captures shown south of 30°S in the southern winter in both the Pacific and Indian Oceans (Figure 2b) could be due to (a) the spawning seasons not being coincident with the designated 6-month period, much as was the case in the Hawaiian area, (b) larvae taken in waters nearer the lower temperature limit, or (c) larvae taken in years when the southward shift of warm water was at its maximum.

Although it may be generalized that spawning occurs throughout the year in tropical waters, Honolulu Laboratory data indicate that seasonal differences may sometimes occur there. Plankton net tows made at 3-month intervals over a 14-month period at five stations along long.

145°W between lat. 12°N and 3°S resulted in no larval skipjack tuna captures in one or more seasons at each of the site sampled, and no
able 1 captures at all sites sampled in winter (Table 1).

RELATIVE ABUNDANCE

Past attempts at measuring relative abundance have relied primarily upon catch rates. Ueyanagi (1969) compared the relative abundance of skipjack tuna larvae, including that of other tunas, across the equatorial Pacific between 0° and 10°N. His comparison was based on the average catch (catch per tow) of larvae taken in 15-min surface horizontal tows with a 1.4-m net. His results indicated an
Fig. 3 increase in the density of skipjack tuna larvae westward (Figure 3), but because the comparison was restricted to only 10° latitude and did not include areas of heavy spawning outside of the 0°-10°N zone, his results may not truly represent larval skipjack tuna abundance across the entire Pacific.

Matsumoto (1975) also attempted measuring relative abundance of skipjack tuna larvae across the Pacific. Using data from various sources, he adjusted the catches made with different net sizes and towing durations, and included tows taken only during spawning seasons from a
Table 2 wider latitudinal range than Ueyanagi (Table 2). The high spawning densities between long. 140°W and 160°E, with the peak at slightly
Fig. 4 east of 180° (Figure 4), differed from Ueyanagi's results. One probable weakness in the results was the relatively small numbers of

tows in the central and eastern Pacific. However, the similarity in the catch trends of both larval and adult skipjack tuna, the latter taken on tuna longline in areas and seasons comparable to those of larval captures, suggests that the limited number of net tows had not noticeably biased the results.

PREDICTING AVAILABILITY FROM LARVAL DATA

(a) Past attempts.--Attempts to predict the availability or potential production of harvestable skipjack tuna have been made by the Japanese. Ueyanagi (In Kikawa, Koto, Shingu, and Nishikawa 1969) estimated a skipjack tuna resource of 800,000 to 1,000,000 metric tons (MT) in the Pacific Ocean on the basis of larval occurrences and 300,000 to 400,000 MT in the Indian Ocean on the basis of proportionate favorable spawning areas in the two oceans. Suda (In Kawasaki 1972) elaborated on these estimates by saying that since 1.7-1.8 times (rounded to 2) more skipjack tuna larvae were taken in plankton tows than larvae of all other tunas, the spawning stock of skipjack tuna was also roughly 2 times that of other tunas and that therefore the potential production of skipjack tuna should be at least 2 times more than that of all other tunas. Since the annual production of large tunas from the Pacific is 400,000 to 500,000 MT, the potential production of skipjack tuna was between 800,000 and 1,000,000 MT. He further believed that, on the basis of ocean areas (probably of areas suitable for skipjack tuna), there was a standing stock of 200,000 to 400,000 MT of skipjack tuna in each of these oceans.

Both Kawasaki (1972) and Matsumoto (1974) felt that Suda's projection of adult skipjack tuna catch from larval abundance was oversimplified. By citing differences in fecundity and average body sizes between skipjack and other tunas, Matsumoto showed that Suda's conversion ratio of 2:1 in favor of the skipjack tuna was not logical. One other important factor not taken into account by Suda was the difference in the efficiency of the different types of gear used in taking the various species of tunas and the effect this would have on the conversion ratio.

(b) Other approaches.--A better approach in using larval data to predict availability of adults would be to consider the skipjack tuna apart from other tunas. This would eliminate the need to adjust for fish size, where all other tunas are grouped into one, size of spawnings (which also vary greatly by species and fish size), and for the vast differences in the efficiency of fishing gear presently used in catching the various species of tunas (longline versus pole and line and purse seine). Furthermore, if we accept Fujino's (1972) separation of the skipjack tuna population into a western Pacific subpopulation and central-eastern (C-E) Pacific subpopulation as being valid, and we consider that the western subpopulation is now being harvested at near its maximum yield (some authors already believe that the catch in the western Pacific cannot be increased appreciably), then we can make a more reliable estimate of the skipjack tuna potential in the Pacific Ocean.

For example, assuming that the figures of relative abundance given by Matsumoto (1975) and discussed above are valid, the catch per tow of skipjack tuna larvae east of 180° projects to be 2.32 times that west of 160°E (omitting for the present the data from long. 160°E-180°, since the boundaries of the two subpopulations run through there with possible mixing occurring at those boundaries. If we further assume that larval abundance in the western Pacific is proportional to the adult population there and that the same proportionality holds true in the central and eastern Pacific, we could estimate the harvestable C-E subpopulation of skipjack tuna to be about 464,000 MT, based on 200,000 MT as representing the present harvest in the western Pacific. But, since nearly 100,000 MT are now being harvested in the central and eastern Pacific, roughly only 360,000 MT of additional skipjack tuna could be taken there. The total potential harvest of skipjack tuna in the Pacific Ocean thus would be somewhere slightly above 660,000 MT, well below the 800,000-1,000,000 MT estimated by Ueyanagi and Suda.

Although the procedure followed here in obtaining the estimates may be an improvement over that used by Ueyanagi and Suda, the accuracy of the estimates could be contested because the estimates are based on relatively few plankton tows in the areas east of long. 180° (Table 2).

REMARKS ON PAST DATA

It is unfortunate that despite the numerous plankton net samples collected to date throughout the Pacific Ocean, involving effort in decades and tows in the thousands, the larval skipjack tuna catch data from the western and central Pacific cannot be compared directly, owing to differences in net sizes and towing methods used. Initially, probably because of the need for large numbers of larvae to permit studies on species identification and developmental stages, Japanese workers resorted to the use of large nets, 1.4 and 2.0 m in diameter, without the use of flowmeters and towed for short periods (15-20 min.) at or near the surface. Such large nets often assured large catches, but the short towing time usually resulted in lower percentage of successful tows (Figure 3) because of patchy distribution of the larvae, unless sampling had occurred in areas of unusually heavy concentrations of patches of larvae. The absence of a flowmeter, of course, made the data suspect for quantitative assessments, since the catch per tow values could be biased considerably, depending upon variations in the towing speed from day to day and from cruise to cruise, from changing weather and sea conditions, and even from towing in directions other than the normal 10° to 15° heading from the prevailing seas.

In the eastern and central Pacific, larval fish sampling has been done primarily with a 1-m net equipped with a flowmeter. The tows, however, were planned mainly for other studies, such as assessment of zooplankton and fish eggs and larvae. Consequently, most of these tows were made to depths well beyond the range of larval tunas. Some sampling at or near the surface have been done in the central and eastern Pacific, but the number and areal coverage by such tows has not been adequate enough for assessing larval tuna abundance on an oceanwide basis (Table 2).

Some years ago the Working Party on Method of Collecting Tuna Larvae, FAO Expert Panel for the Facilitation of Tuna Research, recommended the use of a 1-m plankton net with flowmeter and a 30-min. oblique tow to 60 m as the standard for sampling tuna larvae (Matsumoto et al. 1966). However, sampling for tuna larvae since then has been at a low level and the recommended tow has not come into general usage due to various reasons. In the eastern Pacific, for example, where tows to 200 m have been the standard for many decades to monitor all fish larvae, a shallower tow would have been inadequate for their purpose, and making an additional tow specially for tuna larvae would have meant doubling the cost of processing the samples; a cost most agencies would not be able to bear.

ACTION AND STUDIES REQUIRED

(a) Although adding a special plankton net tow for tuna larvae to the existing sampling procedures would entail added costs, such an attempt must be made if we wish to obtain more information from larval tuna data. One way to reduce the cost of an added tow would be to sort

the samples for tuna larvae at sea prior to fixing them in Formalin.[2] This was done on several occasions by the Honlulu Laboratory with good results. Although sorting at sea is difficult at times, especially during rough weather, sorting freshly caught samples only for tuna larvae, was found to be much easier and required less time (less than an hour for most 30-min. samples) than sorting through preserved samples.

(b) Future north-south sampling transects should extend between the 24°C isotherms in the northern and southern hemispheres or at least between lat. 20°N and 20°S, with nearly equal runs within each 15°-20° longitude interval across the entire Pacific Ocean. Sampling, of course, should be done with a uniform net towed in an identical manner.

(c) During the time the samples are being accumulated, experimental work comparing the 2- and 1-m nets, and the 1.4- and 1-m nets, should be initiated to obtain a more reliable conversion factor from the existing data and to derive a better usable measure of abundance across the Pacific Ocean.

---

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

LITERATURE CITED

CHEN, S. C., and T. H. TAN.

1973. A preliminary report on occurrence of tuna larvae in waters adjacent to Taiwan and South China Sea. Rep. Inst. Fish. Biol. Minist. Econ. Aff. Natl Taiwan Univ. 3:158-172.

FUJINO, K.

1972. Range of the skipjack tuna subpopulation in the western Pacific Ocean. In K. Sugawara (editor), The Kuroshio II, Proceedings of the Second Symposium on the Results of the Cooperative Study of the Kuroshio and Adjacent Regions, Tokyo, 28 September-1 October 1970, p. 373-384. Saikon Publ. Co., Tokyo.

KAWASAKI, T.

1972. The skipjack tuna resource. [In Jap.] Suisan Shūhō (The Fishing and Food Industry Weekly) 660:32-38, July 15, 1972. (Engl. transl., 1973, In U.S. Nat'l. Mar. Fish. Serv., Mar. Fish. Rev. 35(5-6):1-7.

KIKAWA, S., T. KOTO, C. SHINGU, and Y. NISKIHAWA.

1969. The status of the tuna fisheries of the Indian Ocean as of 1968. Far Seas Fish. Res. Lab., S. Ser. 2, 28 p.

KLAWE, W. L.

1963. Observations on the spawning of four species of tuna (Neothunnus macropterus, Katsuwonus pelamis, Auxis thazard, and Euthynnus lineatus) in the eastern Pacific Ocean, based on the distribution of their larvae and juveniles. Inter-Am. Trop. Tuna Comm., Bull. 6:449-540.

KLAWE, W. L.

1970. Scombrid larvae. In C. M. Love (editor) EASTROPAC Atlas, vol. 4, Biological and nutrient chemistry data from principal participating ships, first and second monitor cruises, April-July 1967. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 330, 5 p. + figs.

1971. Scombrid larvae. In C. M. Love (editor) EASTROPAC Atlas, vol. 2, Biological and nutrient chemistry data from principal participating ships, first survey cruise, February-March 1967. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 330:vii + figs.

1972. Scombrid larvae. In C. M. Love (editor) EASTROPAC Atlas, vol. 6, Biological and nutrient chemistry data from principal participating ships, second survey cruise, August-September 1967. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 330:vi + figs.

1974. Scombrid larvae. In C. M. Love (editor) EASTROPAC Atlas, vol. 8, Biological and nutrient chemistry data from principal participating ships and Oceanographer, third and fourth monitor cruises, October 1967-January 1968. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 330:vii + figs.

MATSUMOTO, W. M.

1958. Description and distribution of larvae of four species of tuna in central Pacific waters. U.S. Fish Wildl. Serv., Fish. Bull. 58:30-72.

1974. The skipjack tuna, Katsuwonus pelamis, an underutilized resource. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 36(8): 26-33. (MFR Paper 1077).

MATSUMOTO, W. M.

1975. Distribution, relative abundance, and movement of skipjack tuna, Katsuwonus pelamis, in the Pacific Ocean based on Japanese tuna longline catches, 1964-67. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-695, 30 p.

MATSUMOTO, W. M., W. L. KLAWE, W. J. RICHARDS, and S. UEYANAGI.

1966. Working Party Report on methods of collecting larvae. FAO Fish. Rep. 37:20-34.

NAKAMURA, E. L., and W. M. MATSUMOTO.

1967. Distribution of larval tunas in Marquesan waters. U.S. Fish Wildl. Serv., Fish. Bull. 66:1-12.

STRASBURG, D. W.

1960. Estimates of larval tuna abundance in the central Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 60:231-255.

UEYANAGI, S.

1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, Thunnus alalunga. Bull. Far Seas Fish. Res. Lab. (Shimizu) 2:177-256.

Table 1.--Larval skipjack taken in plankton net tows along long. 145°W.

Month (Season)	May (Spring)	July (Summer)	October (Fall)	January (Winter)	April (Spring)
Location	Larvae/1000m^3 (No. of tows)				
12°00'N	0.05(11)	0.05(12)	0.04(15)	0.00(16)	0.00(14)
7°30'N	0.20(15)	0.00(14)	0.17(15)	0.00(9)	0.20(13)
3°30'N	1.23(15)	0.05(15)	0.00(17)	0.00(6)	0.00(15)
0°	0.14(12)	0.65(15)	0.00(15)	0.00(15)	2.91(15)
3°30'S	0.04(14)	2.45(15)	0.14(17)	0.00(12)	1.11(15)

Table 2.--Catch rates of larval skipjack in night surface tows across the Pacific Ocean.

Longitude	Latitude	Quarter sampled	Net diameter	Duration of tow	Number of tows	Total larvae	Conversion factor	Adjusted catch	Adjusted larvae per tow
			Meter	*Minutes*		*Number*			
80°-100°W	4°-15°N	I, II	1	30	33	7	[2]1.836	12.85	0.39
100°-120°W	10°-15°N	II	1	30	10	11	[2]1.836	20.20	1.63
100°-120°W	0°-7°S	I	1	30	12	19	[3]0.827	15.71	
120°-140°W	10°S-10°N	I, IV	1	30	21	42	[3]0.827	34.73	1.65
140°-160°W	10°S-20°N	I, III	1	30	32	239	[3]0.827	195.18	6.10
160°W-180°	10°S-20°N	I, II, III	1	30	45	389	[3]0.827	321.70	7.15
160°E-180°	10°S-20°N	I, III	1	30	6	45	[3]0.827	37.22	4.94
160°E-180°	10°S-20°N	II, IV	2	20	44	560	[4]0.375	210.00	
140°-160°E	10°S-20°N	II, III, IV	2	20	112	562	[4]0.375	210.75	1.88
120°-140°E	0°-20°N	II, IV	2	20	141	581	[4]0.375	217.88	1.54

[1]Conversion factor is the ratio of standard to average volume of water strained. Standard volume used was 1,454 m^3.

[2]Computed from average volume of 792 m^3 from 62 tows in the eastern Pacific. (Data from Klawe 1963.)

[3]Computed from average volume of 1,759 m^3 from 289 tows in the central Pacific. (Data from BCF Biological Laboratory, Honolulu files and Strasburg 1960.)

[4]Computed from estimated volume of 3,878 m^3, the volume strained at a given towing speed of 1.03 m/s (2 knots) in the western Pacific. (Catch data from Ueyanagi 1969.)

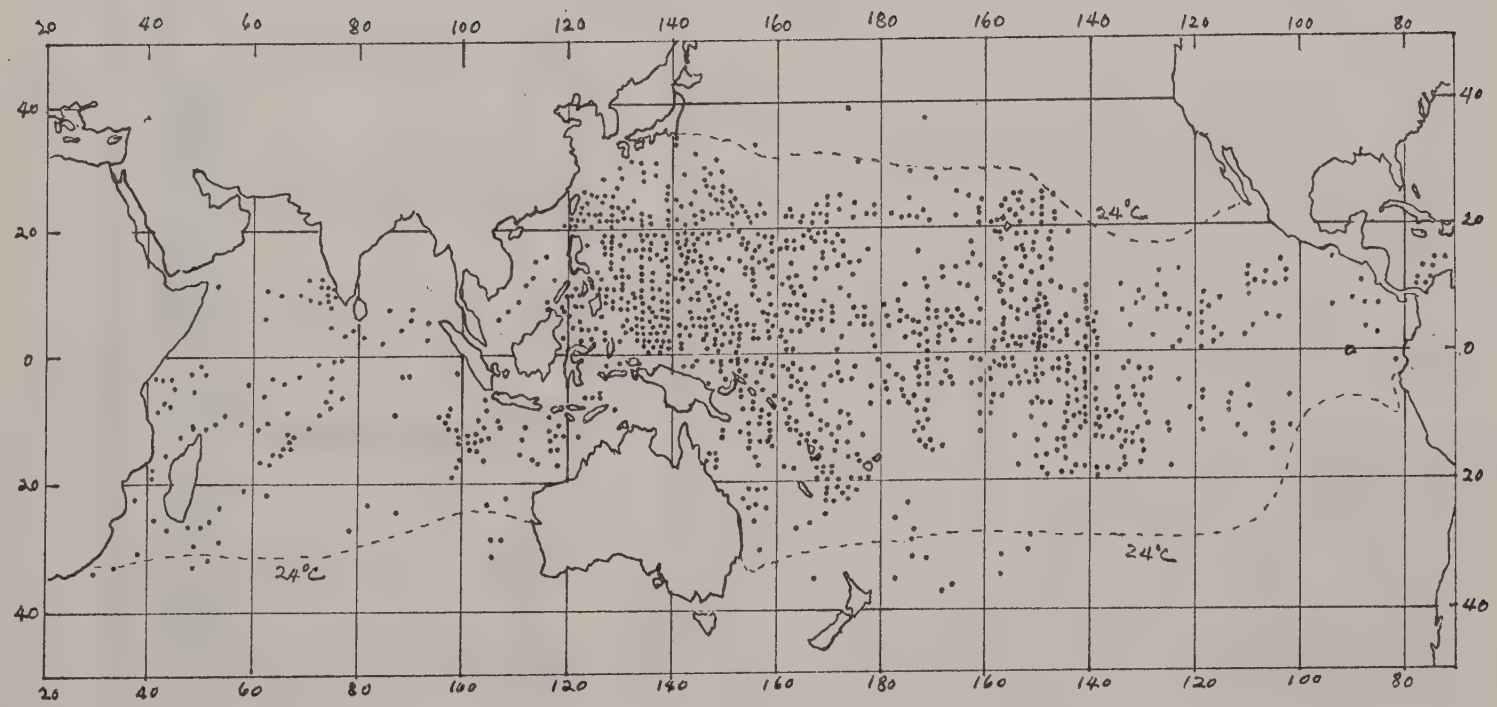


Fig. 1.--Capture sites of skipjack larvae in the Pacific and Indian Oceans. Each dot represents presence of larvae.

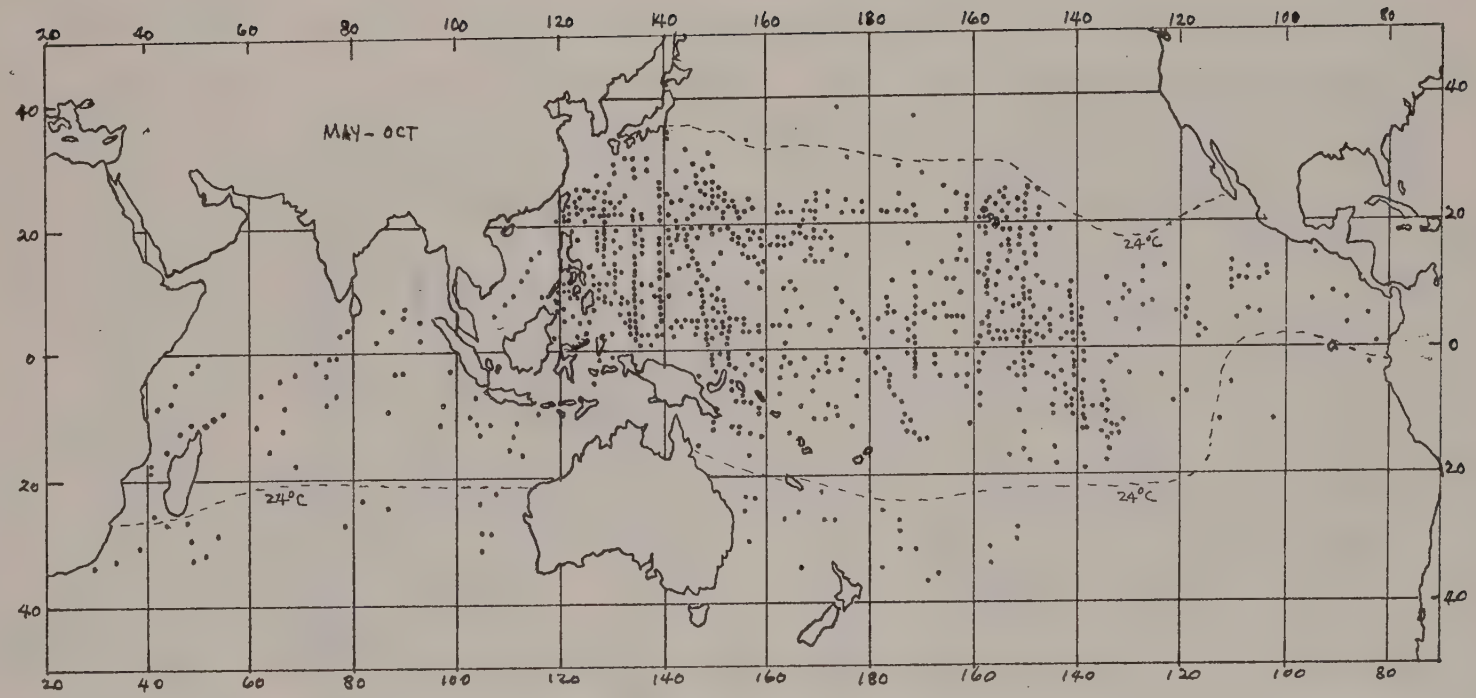


Fig. 2a.--Sites of larval skipjack captures during May-October.

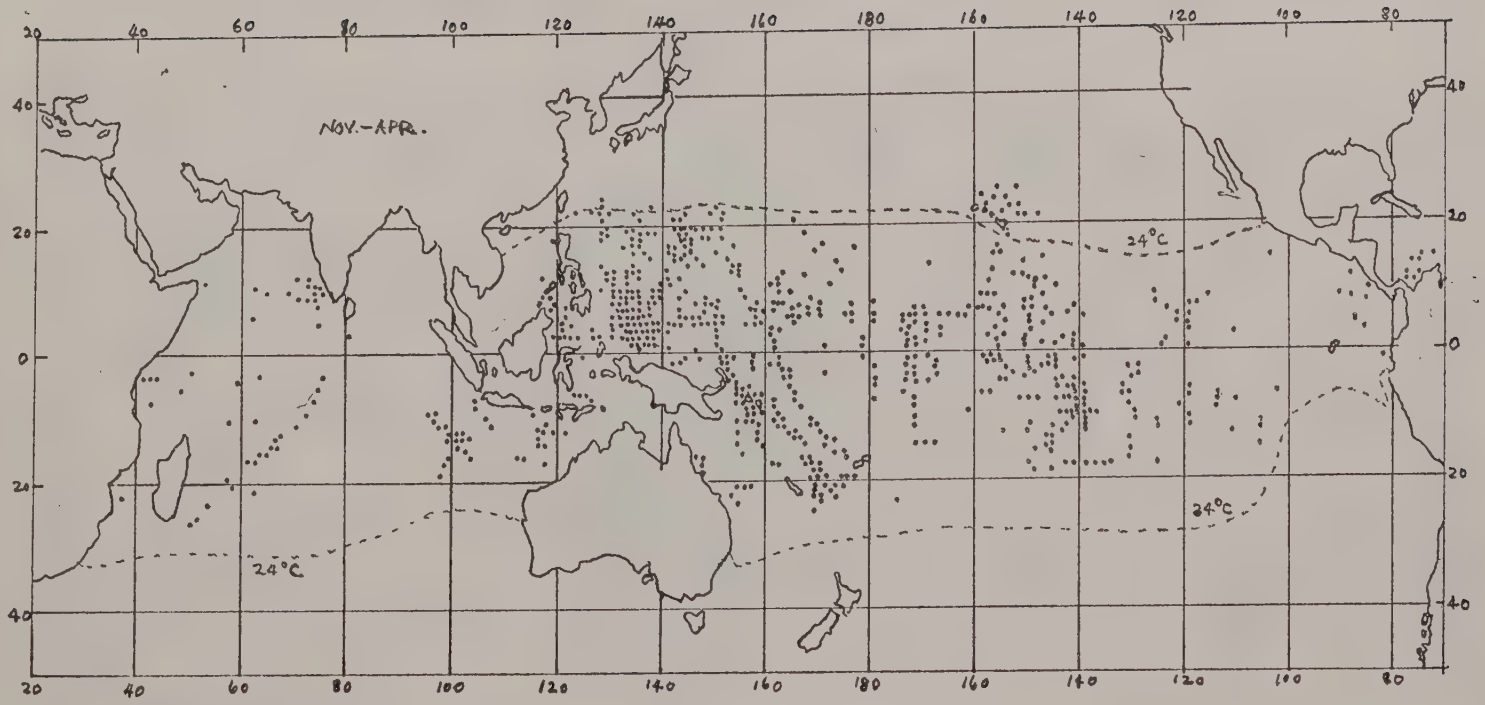


Fig. 2b.--Sites of larval skipjack captures during November-April.

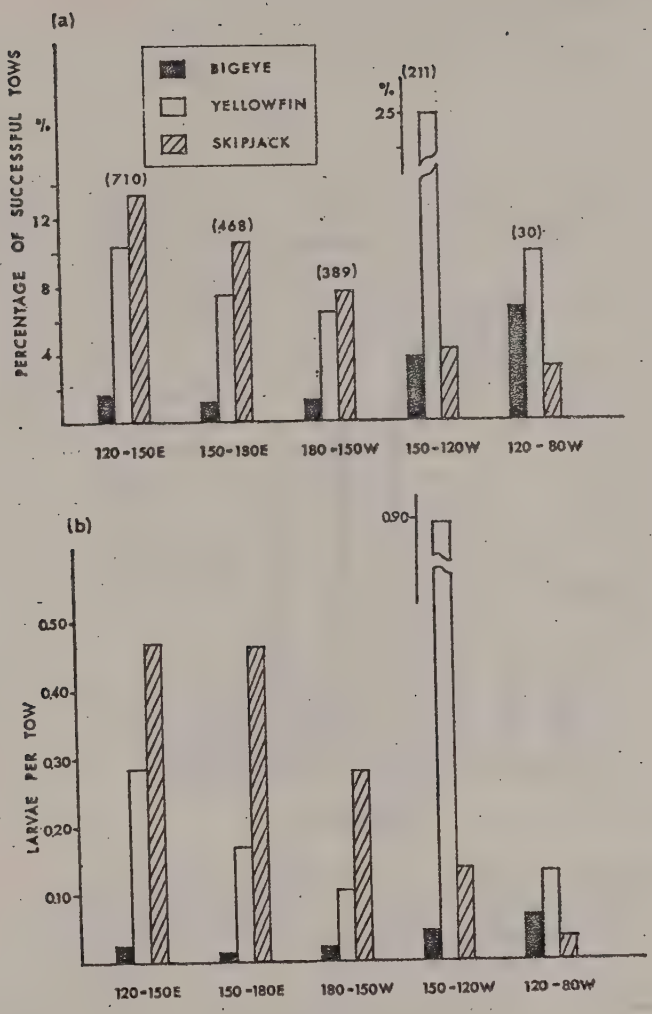


Fig. 3.--Occurrence and relative abundance of tuna larvae in the equatorial Pacific between lat. 0° and 10°N(Number of tows in parentheses).

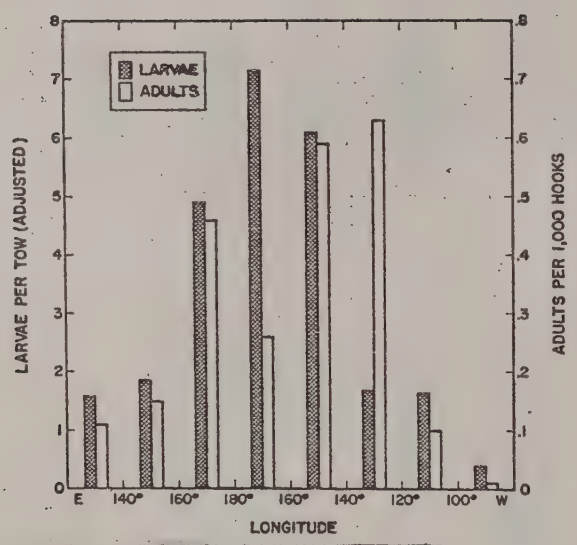


Fig. 4.--Catch rates of skipjack larvae and adults across the Pacific between lat. 10°S and 20°N.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu and La Jolla Laboratories
P. O. Box 3830
Honolulu, Hawaii 96812

TO ALL BILLFISHERS:

For 15 years the National Marine Fisheries Service (NMFS) and the Hawaiian International Billfish Tournament (HIBT) have cooperated in the collection and dissemination of scientific information at the tournament. HIBT officials institute and arrange tournament procedures, and provide equipment and supplies to make it possible for NMFS observers to gather data. Both organizations cooperate to make HIBT an educational as well as an enjoyable experience by providing demonstrations, workshops, lectures, projects, and exhibits on game fish oriented science. NMFS analyzes the tournament data and issues a current report of each tournament. This is the report for the Eighteenth HIBT. NMFS also stores the data to be reviewed and analyzed periodically from a more encompassing perspective.

A special visiting biologist from New Zealand, Peter Saul, joined the science team of Ray Sumida and myself. Peter was sponsored by the New Zealand Game Fish Council to familiarize himself with ongoing research on billfishes.

The accomplishment of our work at the tournament depended on the cooperation and the assistance of anglers, the tournament staff and officials, and the volunteers from the community. The three of us thank you for your generous support which not only made it possible for us to do our work but made it enjoyable as well.

THE CATCH

This year the catch consisted of 47 blue marlin, 1 black marlin, 3 striped marlin, 5 shortbill spearfish, and 32 ahi (yellowfin tuna). Table 1 lists the catches at HIBT since 1962. From the number of boat-days per fish (extreme right column of Table 1) one can see that this year's fishing was the least efficient since 1969, which is the last year before tournaments were scheduled to coincide with the new moon.

It also equals the best year (1967) prior to 1970, the first year that HIBT has been scheduled to coincide with the new moon.

What the blue marlin lacked in numbers, especially when compared to the past two extraordinary years (1974-75), they made up for it in size. The average weight of the blue marlin landed was 313 lb. Their average weight in 1975 was 207 lb. The weight range of the blue marlin was 84-745 lb and half of them weighed in more than 274 lb. Seven blue marlin weighed over 500 lb. At no other HIBT have so many fish weighing over 500 lb been caught.

The ahi weights ranged from 104 to 250-1/2 lb and averaged 164 lb. The striped marlin averaged 58 lb; the smallest weighed 41 lb and the largest 58 lb. The shortbill spearfish weighed 31-1/2 to 51 lb. The average weight for this species was 38 lb. The lone black marlin weighed 232 lb.

The most unusual phenomenon of the tournament was the predominance of female blue marlin over males. Of 44 fish examined 37 were females and 7 males. NMFS records of the tournament for the past 15 years show that males always outnumbered females by as much as a ratio of 8:1 (Table 2). The turnabout ratio of 5.3 females to 1 male is certainly a surprise, although I must admit that I don't know its significance. Perhaps the males are finally getting smarter.

FISHING AREAS

Your thrice daily reports to *Longnose* were fed to the data machine which regurgitated the statistics in this section. Area *Lima* with 477 boat-hours of fishing was the preferred area. Areas *Kilo* and *Sierra* which had 395 and 382 boat-hours, respectively, followed closely in preference. Other popular areas, those with over 100 boat-hours, listed in order were: *Tango*, *India*, *Juliett*, *Uniform A*, *Uniform B*, and *Mike*. The following analyses were limited to these areas.

Area *Kilo* was the most productive area (Table 3). The catch in this area of 11 blue marlin, 1 striped marlin, 2 shortbill spearfish, and 8 ahi totaled 4,985 lb. Area *Lima* was second with 3,559 lb of fish. When the data were examined in relation to the number of boat-hours, the rankings of the most productive area changed somewhat. Area *Kilo* still remained high on the list but *Lima* because of its high number of boat-hours dropped to fifth or sixth on the list. The rankings of the areas in several categories are summarized in Table 4.

The overall strike rate for 1976 was 0.11 strikes per boat-hour. The average strike rate for the past 4 years was 0.20, almost twice of this year's. The difference between this year's rate and the 0.20 average of the past 4 years is striking. By yesteryears' standards, this year's strike rates in all of the areas would be considered low. The area ratings in Figure 1, therefore, are to be viewed in a context relative to this year's strike rates.

An innovation to the radio reporting procedure was made this year. As each team reported, the data were fed into a small computer. Within seconds after the report of the last team the computer printed out the strike rates for each area for the day. Information on the most active areas were immediately broadcast to the teams by *Longnose*. I would like your reaction to the broadcast, more specifically, whether you would like to see it continued or not.

TACKLE, TIDES, AND TIME

The percentage of fish landed on 80-lb test line was 63.6% this year. This is the highest percentage landed on 80-lb test since 1970 (Figure 2). Of the rest of the fish 31.8% were caught on 50-lb test line and 4.6% were caught on 130-lb test line. The percentage of hook-ups landed increased to 58%, the highest to date (Figure 2). I would like to interpret this statistic as meaning that your fishing skills have improved but at this point I don't have sufficient data to show that it is not within the range of chance fluctuations.

I think it would be interesting to determine the fishing effectiveness of lines of various strengths. That determination will have to wait for another day, however. We did not collect data for that analysis.

I continue to look for that elusive relationship between tide phase and fish availability. In Figure 3 the strike rates calculated from the radio reports are superimposed on the tide chart of the tournament period. No relationship is obvious. The fact that HIBT catches have improved outstandingly since the tournament has been scheduled to coincide with the new moon implies a relationship. Data of the past 6 years have been teasingly suggestive. And it still remains a puzzle.

Ahi catches were well distributed throughout the day. The blue marlin catches, on the other hand, showed a peak period during the 11-12 o'clock hour (Figure 4). In 1975 the same hour was also the best for blue marlin. Moreover, except for the hour of 9-10 o'clock, the hourly distribution patterns of blue marlin catches for 1976 and 1975 (Figure 5) are strikingly similar. Coincidence?

STOMACH CONTENTS

Forty-six blue marlin were dissected and their stomachs examined. The results are listed in Table 5. The species of fish that occurred in more stomachs than any other species was the opelu. It was found in 14 stomachs or 34% of the stomachs examined. Skipjack tuna occurred in 13 stomachs and was the most important food item in numbers and in bulk. Seventy-one percent of the blue marlin stomachs contained one or more species of tuna. Squid, another popular diet item, occurred in 24% of the stomachs.

Several stomachs had unusual items in them. One stomach contained two juvenile broadbill swordfish. One of the juveniles was 65 cm (26 in.) long; the other was too digested to be measured. A wahoo (ono) measuring 112 cm (44 in.) in length was in another stomach. The other unusual item was a 16-lb skipjack tuna. Although this species is one of the more common items in blue marlin stomachs, the largest ones are usually about 4 lb.

CONFERENCE

An informal conference was chaired by Richard Boone on Saturday, July 31, to discuss the Fishery Conservation and Management Act of 1976 and recreational fishing. Principal speakers were Mr. Richard Shomura, Director of the Honolulu Laboratory, NMFS, and Dr. Jerry Wetherall, biologist at the Honolulu Laboratory. The discussion was spiced with an international flavor when the following individuals contributed viewpoints of their country's positions: Peter Saul and John Chibnall, New Zealand; Harry Graham, Ecuador; Peter Goadby, Australia; Leo Langomazino, Tahiti; George Wall, Fiji; Richard Cheetham, South Africa; and Robert Smith and Frank Moss, United States.

At the conference Richard Boone eloquently presented the intentions of the Pacific Gamefish Foundation, an organization formed for the purpose of conserving life in the sea by promoting the collection of data and the exchange of information between scientists and recreational fishermen.

Until the Nineteenth Hawaiian International Billfish Tournament,

Aloha,

Heeny S. H. Yuen

Heeny S. H. Yuen
Leader, Recreational Fisheries

Attachments

November 10, 1976

Table 1.--Numbers of qualifying game fish landed and teams fishing during Hawaiian International Billfish Tournaments, 1962-76.

Year	Blue marlin	Black marlin	Striped marlin	Shortbill spearfish	Sailfish	Yellowfin tuna ≥100 lb	Total qualifying fish	Number of teams	Number of boat-days fishing per fish[1]
1962	30	1	--	--	1	19	51	68	6.7
1963	19	2	1	--	--	26	48	72	7.5
1964	31	--	1	--	--	2	34	69	10.1
1965	47	--	--	--	--	9	56	78	6.9
1966	26	3	2	--	--	7	38	72	9.5
1967	63	--	1	--	--	18	82	68	4.2
1968	36	2	4	--	--	4	46	85	9.2
1969	32	1	--	--	--	4	37	75	10.1
1970	91	--	2	--	2	14	109	73	3.3
1971	41	--	3	1	--	47	92	77	3.4
1972	77	--	--	--	--	11	88	59	3.4
1973	76	--	1	3	1	17	98	61	3.1
1974	66	2	1	6	--	37	110	64	2.9
1975	104	--	2	8	--	79	193	79	2.0
1976	47	1	3	5	--	32	88	74	4.2

[1]Nine-hour fishing days, 1962-73; 8-hour days, 1974-76.

Table 2.--Sex ratios for blue marlin examined from Hawaiian International Billfish Tournaments, 1962-76.

Year	Number of males	Number of females	Ratio males to females
1962	16	7	2.3:1
1963	13	6	2.2:1
1964	14	12	1.2:1
1965	35	8	4.4:1
1966	16	8	2.0:1
1967	51	13	3.9:1
1968	24	10	2.4:1
1969	23	8	2.9:1
1970	63	14	4.5:1
1971	21	9	2.3:1
1972	64	8	8.0:1
1973	47	21	2.2:1
1974	46	14	3.3:1
1975	70	16	4.4:1
1976	7	37	0.2:1

Table 3.--Number of fish caught by species, date, and area, HIBT 1976.

	Area													
	B	C	E	I	J	K	L	M	N_A	S	T	U_A	U_B	V
Blue marlin														
July 26	—	—	—	—	—	3	—	—	—	—	3	1	1	1
27	—	—	—	—	1	2	1	—	—	2	—	1	1	—
28	—	—	—	—	—	1	2	—	—	2	2	—	—	—
29	—	—	—	1	1	1	4	—	—	1	—	1	—	—
30	—	1	—	1	1	4	2	—	—	3	1	1	—	—
Sum		1		2	3	11	9			8	6	4	2	1
Avg. weight (lb)		168.0		378.0	363.7	323.6	308.3			236.6	297.3	332.2	522.0	303.5
Ahi														
July 26	1	—	—	—	4	3	3	—	—	1	—	1	2	—
27	—	—	—	—	—	1	1	1	—	—	—	—	1	—
28	2	—	—	—	—	1	—	2	—	—	—	—	1	—
29	—	—	1	1	—	1	—	—	—	—	—	—	—	—
30	—	—	—	—	1	2	—	—	—	—	1	—	—	—
Sum	3		1	1	5	8	4	3		1	1	1	4	
Avg. weight (lb)	166.2		206.5	147.5	175.3	162.2	187.9	161.0		112.0	104.0	125.5	157.8	
Black marlin														
July 26	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Weight (lb)										232.0				
Striped marlin														
July 28	—	—	—	—	—	1	—	—	—	—	—	1	—	—
30	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Weight (lb)		75.0				41.0						57.5		
Shortbill spearfish														
July 27	—	—	—	—	—	1	1	—	—	—	—	—	—	—
29	—	—	—	—	—	1	—	—	1	—	1	—	—	—
Sum						2	1		1		1			
Avg. weight (lb)						43.0	33.0		38.0		31.5			

Table 4.--Ranks of areas with more than 100 boat-hours of effort in several categories, HIBT 1976.

Rank	Categories						
	No. of strikes / boat-hour	No. of marlin / boat-hour	Lb of marlin / boat-hour	No. of ahi / boat-hour	Lb of ahi / boat-hour	No. of fish / boat-hour	Lb of fish / boat-hour
1	K	U_A	U_A	U_B	U_B	K	U_B
2	U_B	K	K	M	M	U_B	K
3	J	T	U_B	J	J	U_A	U_A
4	L	S	T	K	K	J	J
5	S	L	L	L*	L	T	T
6	T	U_B	S	U_A*	U_A	L	L
7	M	J	J	I	I	M	S
8	U_A	I	I	T	T	S	M
9	I	M	M	S	S	I	I

*Tie.

Table 5.--Stomach contents of blue marlin, HIBT 1976.

Food items	Date and number of stomachs containing listed food items					Percent occurrence
	July					
	26	27	28	29	30	
Fish						
Tunas and mackerels, Scombridae	7	5	4	4	9	71
Skipjack tuna, *Katsuwonus pelamis*	3	3	2	2	3	32
Kawakawa, *Euthynnus affinis*	–	–	1	1	–	5
Frigate mackerel, *Auxis* sp.	2	–	–	–	4	15
Ono (wahoo), *Acanthocybium solandri*	–	–	–	–	1	2
Unidentified tuna	3	2	2	1	6	34
Broadbill swordfish, Xiphiidae	1	–	–	–	–	2
Opelu, Carangidae	4	–	1	5	4	34
Mahimahi, Coryphaenidae	–	–	1	1	1	7
Triggerfish, Balistidae	1	1	–	–	–	5
Pelagic spiny puffer, Diodontidae	–	1	2	1	–	10
Sharpbacked puffer, Canthigasteridae	–	–	1	–	–	2
Butterflyfish, Chaetodontidae	–	–	2	2	–	10
Surgeonfish, Acanthuridae	–	–	1	1	–	5
Lancetfish, Alepisauridae	–	–	2	1	–	7
Aweoweo, Priacanthidae	–	–	–	1	–	2
Unidentified fish	3	2	–	2	4	27
Invertebrates						
Squid, Decapoda	4	2	1	1	2	24
Octopus, Octopoda	–	–	1	–	–	2
Empty or everted stomachs	1	3	1	2	2	20
Number of stomachs examined	9	8	7	8	14	
Total: 46						

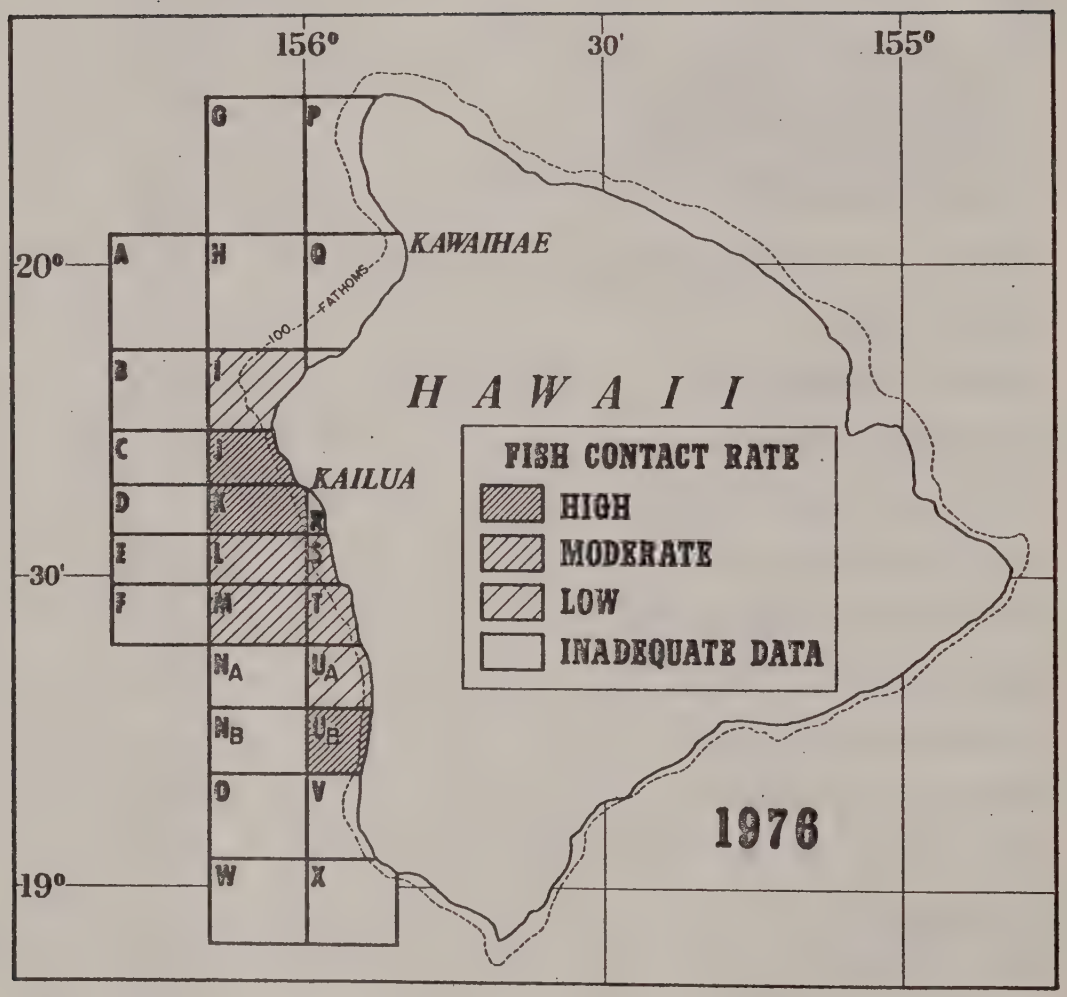


Figure 1.--Strike rates in various fishing areas.

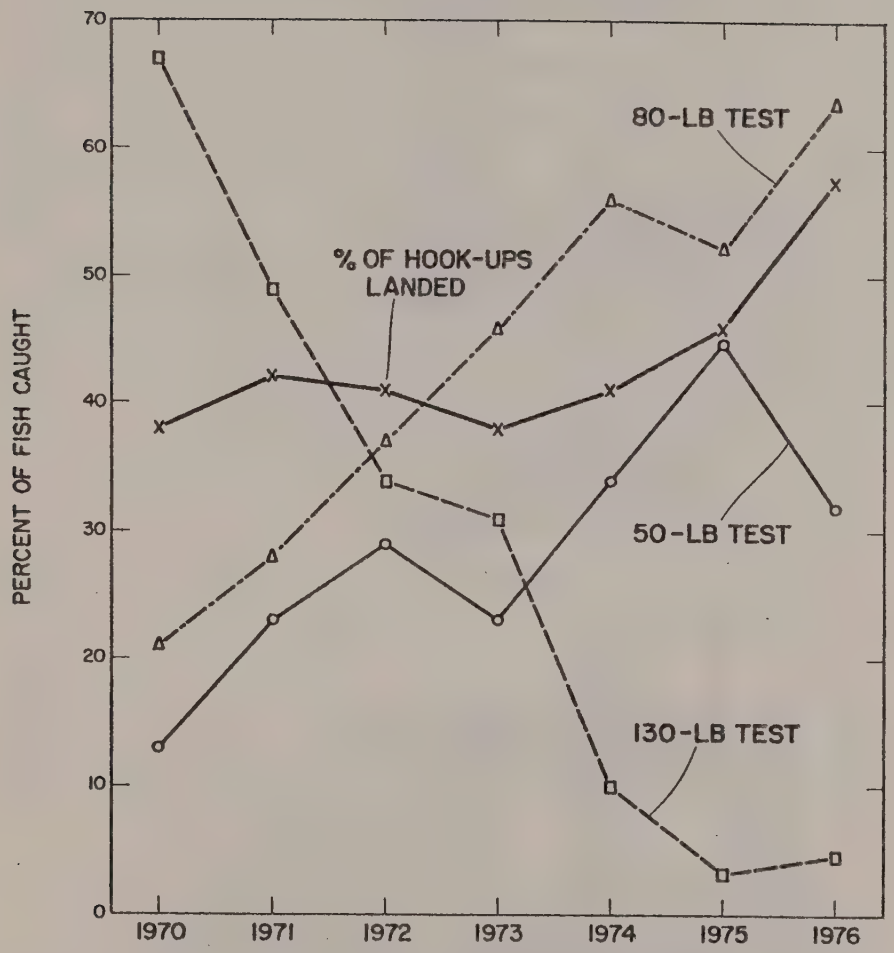


Figure 2.--Proportion of catch landed on lines of various sizes.

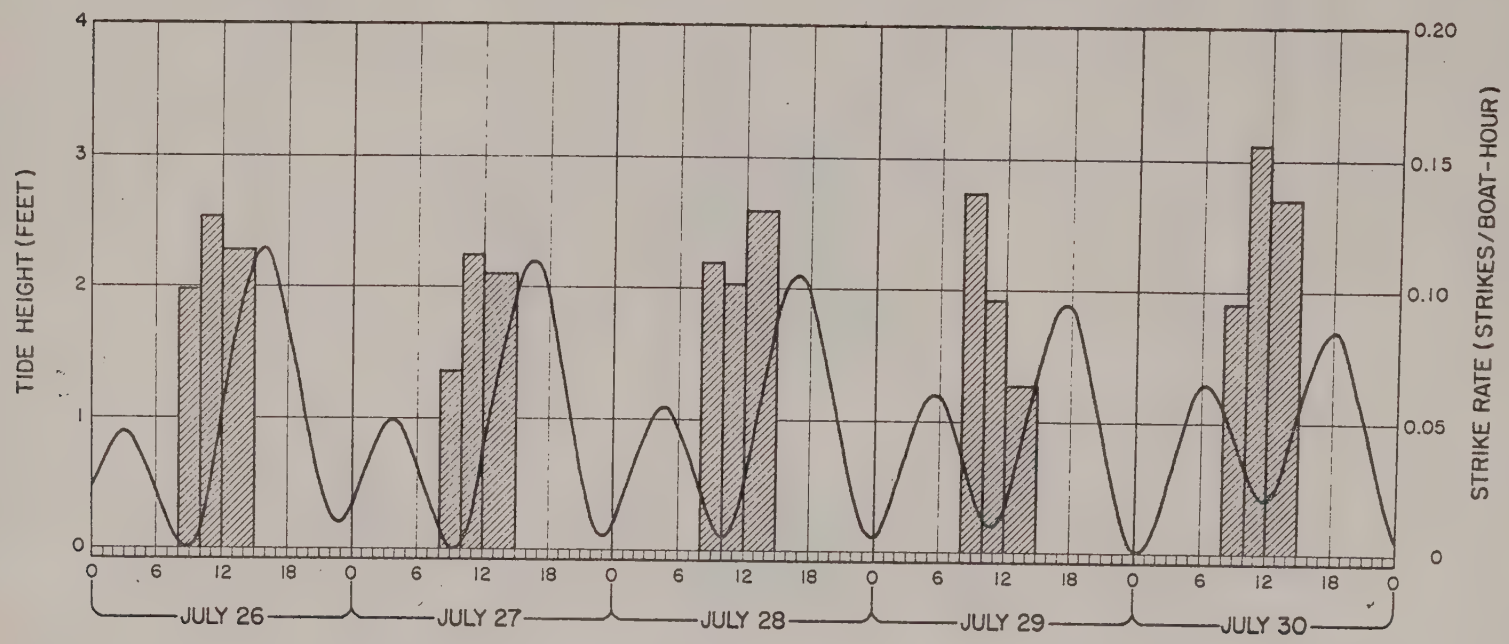


Figure 3.--Strike rates and tide cycle, HIBT 1976.

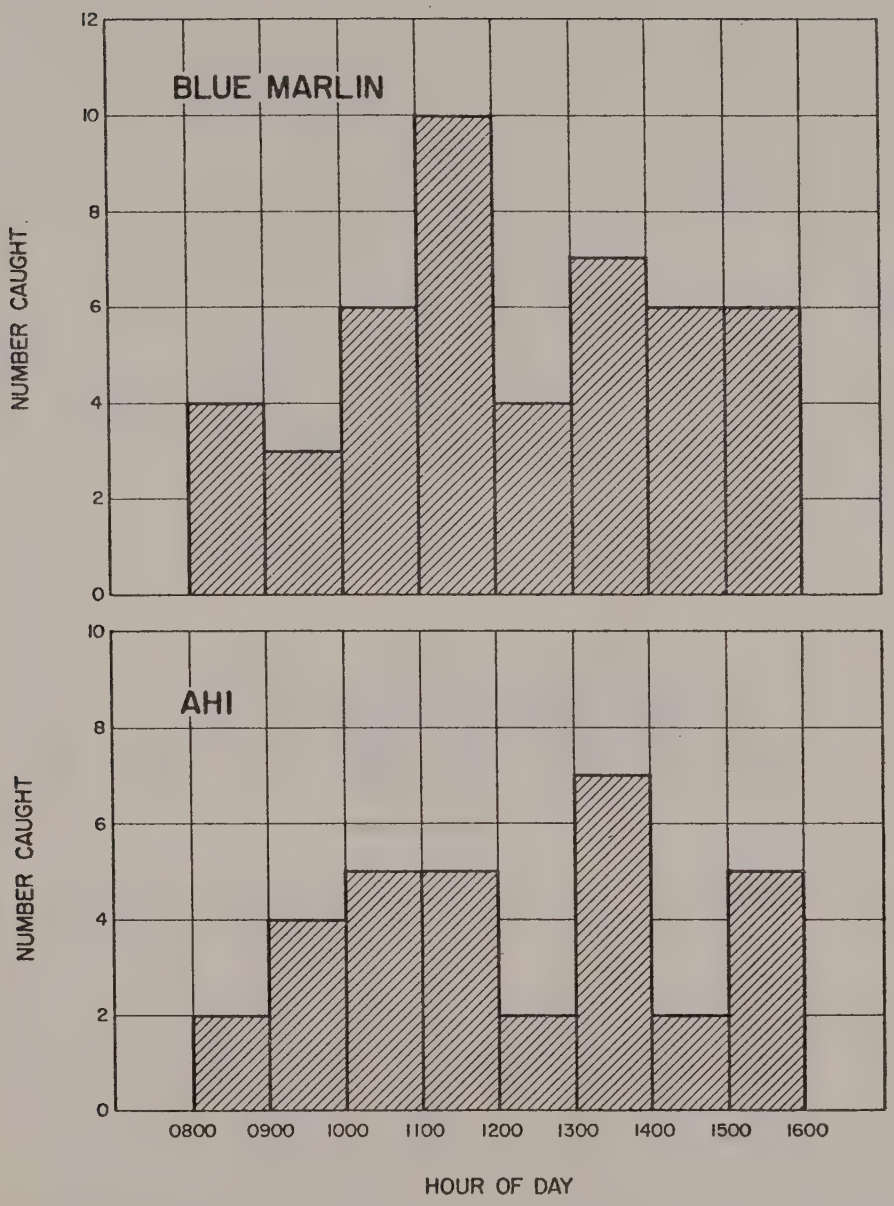


Figure 4.--Number caught and time of day for blue marlin and ahi.

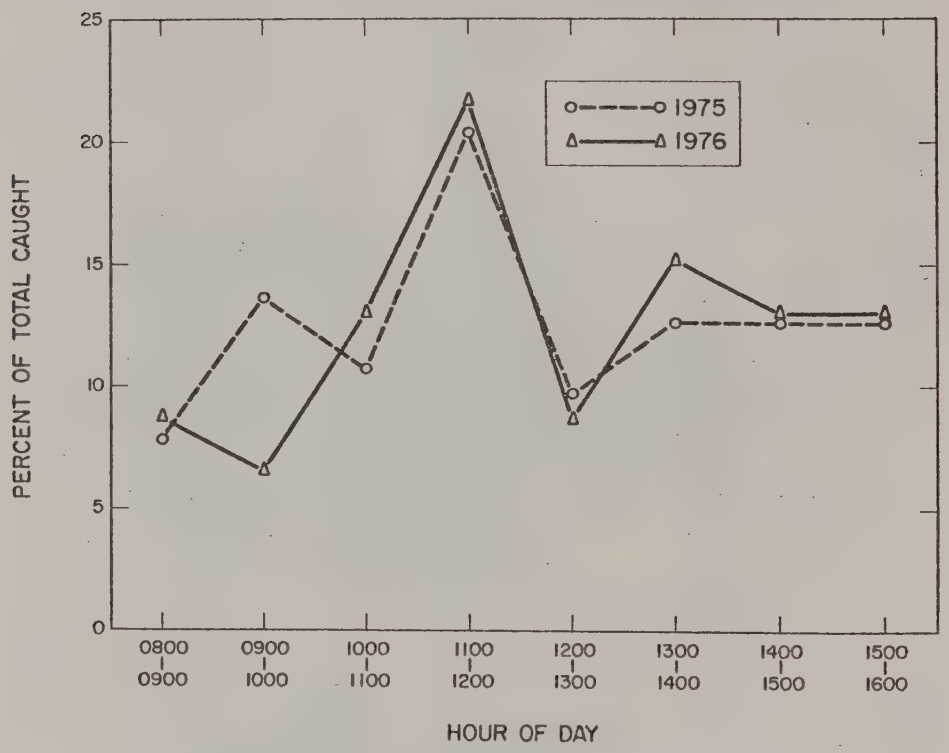


Figure 5.--Time of day blue marlin were caught, HIBT 1975 and 1976.

Southwest Fisheries Center Administrative Report No. 13H, 1976

PRELIMINARY RESULTS OF LOBSTER TRAPPING IN NORTHWESTERN HAWAIIAN ISLANDS WATERS

By

Richard N. Uchida and Thomas S. Hida
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
Honolulu, HI 96812

December 1976

INTRODUCTION

Since mid-1975, the National Marine Fisheries Service's, Southwest Fisheries Center at Honolulu has been engaged in a program to assess quantitatively, the marine resources in waters surrounding the Northwestern Hawaiian Islands (NWHI). The islands, often called the "Leeward Islands," stretch for over 1,000 miles (1,850 km) northwestward beyond the island of Kauai in the major Hawaiian group.

At present, there is a great urgency to know a great deal more about the marine resources of the NWHI. The State of Hawaii, pressed with a growing demand for assessment and rational utilization of its marine resources, recognizes the vital importance of the sea to its economic growth and has fostered a program of harvesting the marine resources of the waters surrounding the entire Hawaiian chain (State of Hawaii 1969, 1974).

Among the preliminary results obtained after four survey cruises to the NWHI was that there is probably a large, unutilized resource of two species of spiny lobsters, *Panulirus marginatus* and *P. penicillatus*, both of which are of great importance in the sport and commercial fisheries of Hawaii. This report presents some of the results that were obtained during our survey cruises.

DESCRIPTION OF TRAPS USED

Two types of traps have been used to capture the major portion of the lobsters during the survey cruises. One is actually a

Hawaiian-type fish trap which, in waters around Oahu, is used primarily to capture fish; lobsters are usually caught incidental to this primary function. Early models of traps used measured 5' x 5' x 4' (1.5 x 1.5 x 1.2 m) and 2' x 2' x 4' (0.6 x 0.6 x 1.2 m) with one or two entrances, but recent survey cruises have switched to traps which are rectangular and measure 5' (1.5 m) long, 3' (0.9 m) wide, and 2' (0.6 m) high with two entrances either round and measuring 5.5" (14 cm) in diameter or oval and measuring 5" (12.7 cm) along the short axis and 9" (22.9 cm) along the long axis. Construction consists of 1" (2.5 cm) square mesh galvanized wire stretched over a 0.5" (1.3 cm) reinforcing rod framework. The second type of trap used is the California two-chambered lobster pot which is rectangular, measures 3.1' (0.9 m) long, 2' (0.6 m) wide, and 1.4' (0.4 m) high, and occupies about a third as much space as the Hawaiian trap. The lobster pot has no reinforcing steel framework; construction consists simply of 2" x 4" (5.1 x 10.2 cm) heavy duty galvanized wire mesh. There are two outer conical entrances measuring 6.5" (16.5 cm) in diameter and another inner entrance of the same diameter between the two chambers which permits the lobsters entering the first chamber from the outside to enter the second chamber which is baited. Bait is placed in a 0.5" (1.3 cm) wire cage. All traps were weighted at the bottom with heavy-duty chains to maintain stability in strong currents and surges.

FISHING STRATEGY

Preliminary tests showed that the traps fished best at night. There were no catches from sets made in daylight hours. Set usually at 1700, the traps baited with 1-5 lb (0.4-2.3 kg) of chopped fish (mackerel, skipjack and yellowfin tunas, kawakawa, goatfish, pink snapper, wahoo, butterflyfish, surgeonfish, triggerfish, and pipefish) soaked overnight for 13-16 h in waters varying in depth from 16 to 65 fathoms (29.3 to 118.9 m). Retrieving lines of 0.5" (1.3 cm) polypropylene rope were attached to a plastic float marked with a flag.

CATCH RATES

Results from an early cruise using the 5' x 5' x 4' (1.5 x 1.5 x 1.2 m) and 2' x 2' x 4' (0.6 x 0.6 x 1.2 m) Hawaiian-type fish traps showed that lobster catches from various locales within the NWHI were quite variable. For example, the best catches occurred off Necker Island where 17 traps set in 16-31 fathoms (29-57 m) produced 160 *P. marginatus* or an average catch of 9.4 lobsters per trap. Closer examination of the data indicated that traps that fished deeper in 24-31 fathoms (44-57 m) of water produced the best catches. At a station north-northwest of Nihoa Island, 11 traps, fished in 24-26 fathoms (44-48 m) of water produced only 41 lobsters or an average catch of 3.7 lobsters per trap. At stations occupied near Pearl and Hermes Reef, Kure Atoll, Lisianski Island, Laysan Island, and Gardner Pinnacles, catches were relatively poor.

During the most recent cruise, lobster catches made by the 5' x 3' x 2' (1.5 x 0.9 x 0.6 m) Hawaiian fish trap and the California lobster pot were the best around Necker Island. Traps were used at each station in two pairs--one pair consisting of one of each of the two types of traps--and spaced 3 fathoms (5.5 m) apart. The distance between each station was 10 fathoms (18.3 m) and six stations constituted one set of 24 traps. Forty-five minutes were required to complete the set and 1.5-2 h needed to retrieve the traps on a power block.

Among the six sets made during the cruise, one set produced a spectacular 428 lobsters. At this particular set, the Hawaiian traps produced 229 lobsters or an average of 19.1 per trap. The California pot, being much smaller in size and total volume, yielded 199 lobsters or an average catch of 16.5 per trap. The maximum catch at one station, consisting of a string of 4 traps, was 106 lobsters or an average of 26.5 per trap. For individual traps, one Hawaiian trap yielded a maximum of 49 lobsters where the maximum for a California pot was 33 lobsters.

SIZE DISTRIBUTION

The lobsters taken on our survey cruises were generally small. Among lobsters taken in traps near Nihoa, Necker, Gardner Pinnacles, Laysan, and Kure, the females were considerably smaller than the males. For 71 females sampled, the weights varied between 0.4 and 2.5 lb (202 and 1,151 gm) and averaged 0.6 lb (256 gm). Among 128 male lobsters,

however, the range in weights was wider, varying from 0.4 to 3.0 lb (205 to 1,374 gm) and averaging 1.5 lb (692 gm).

On our most recent survey cruise, carapace lengths were measured and their distribution, by sex, is shown in Figure 1. Of 923 lobsters measured, 691 (74.9%) were males and 232 (25.1%) were females. Four-hundred and sixty-five (67.3%) of the males and 39 (16.8%) of the females caught were of legal size (minimum legal size in Hawaii is 1 lb or a carapace length 3.25" (8.25 cm)).

MISCELLANEOUS CATCHES

In addition to lobsters, both the Hawaiian trap and California pot caught a variety of fish, some commercially valuable on the Honolulu fresh fish market. On the early cruises, snappers, locally called "opakapaka," *Pristipomoides microlepis*, were caught in fair numbers on four occasions in the large traps that were fished at the shelf edge north of Necker Island in 24-31 fathoms (44-57 m) of water. Catches ranged from 10 to 17 lb (4.5 to 7.7 kg) per trap and average 11.9 lb (514 kg). Near Kure Atoll, one trap, fished at 26 fathoms (48 m) produced 40.5 lb (18.4 kg) of carangids, *Caranx cheilio*. Two traps out of 12 that were fished at Lisianski Island produced 35 and 105 lb (16 and 48 kg) of another species of carangid, *Carangoides ajax*.

On our most recent cruise this past fall, squat lobsters, *Scyllarides squammosus*, moray eels, blue-lined snappers, *Lutjanus kasmira*, opakapaka, *P. microlepis*, moano, *Parupeneus multifasciatus*,

malu, P. pleurostigma, squirrelfishes, Myripristis berndti, and a few other species were also taken in both types of traps.

CONCLUSION

It appears from our preliminary cruise results that at present, the best ground for lobster trapping is in waters around Necker Island. Catch rates were highest along the periphery of the bank near the upper slope zone in about 16 to 30 fathoms (29 to 55 m) of water. Our program of stock assessment in waters of the NWHI is continuing and we hope that in time we will be able to estimate the degree to which the lobster stock can be harvested.

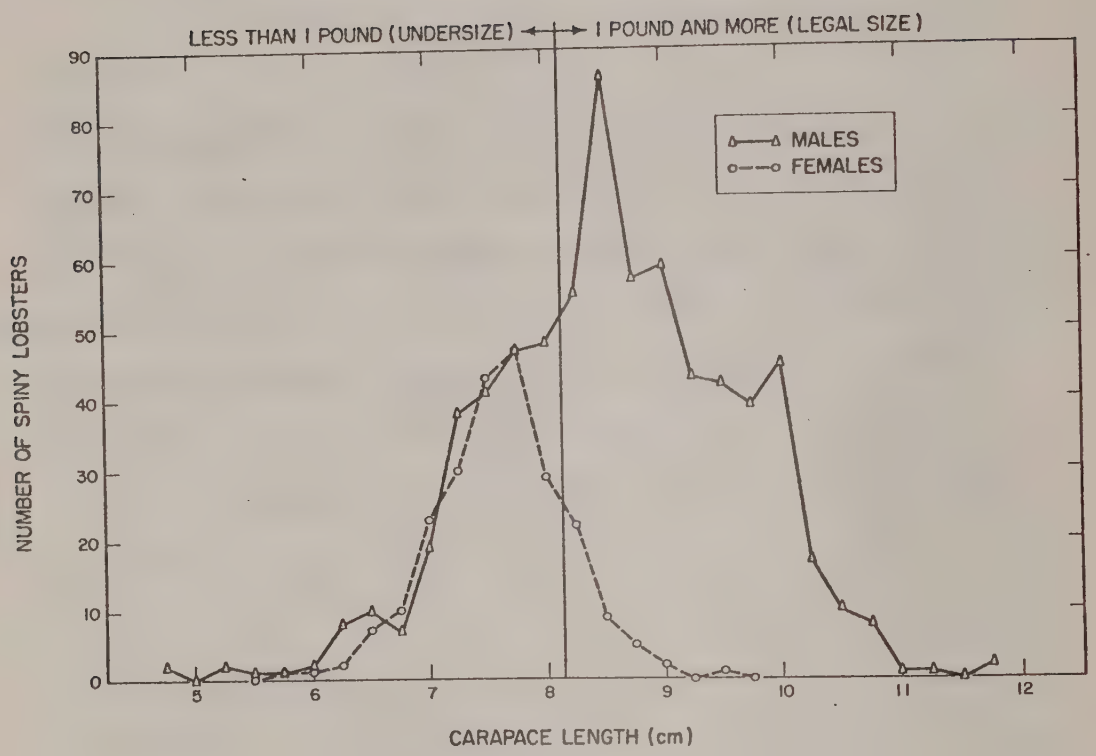


Figure 1.--Carapace length (cm) frequency of spiny lobsters, Panulius marginatus, caught trapping around Necker Island on Townsend Cromwell cruise 76-06-73 (October-November 1976).

LITERATURE CITED

[Hawaii.] State of Hawaii, Department of Planning and Economic Development.

1969. Hawaii and the sea. A plan for State action. Report to the Governor's Task Force on Oceanography, 112 p.

1974. Hawaii and the sea. The Governor's Advisory Committee on Science and Technology, 111 p.